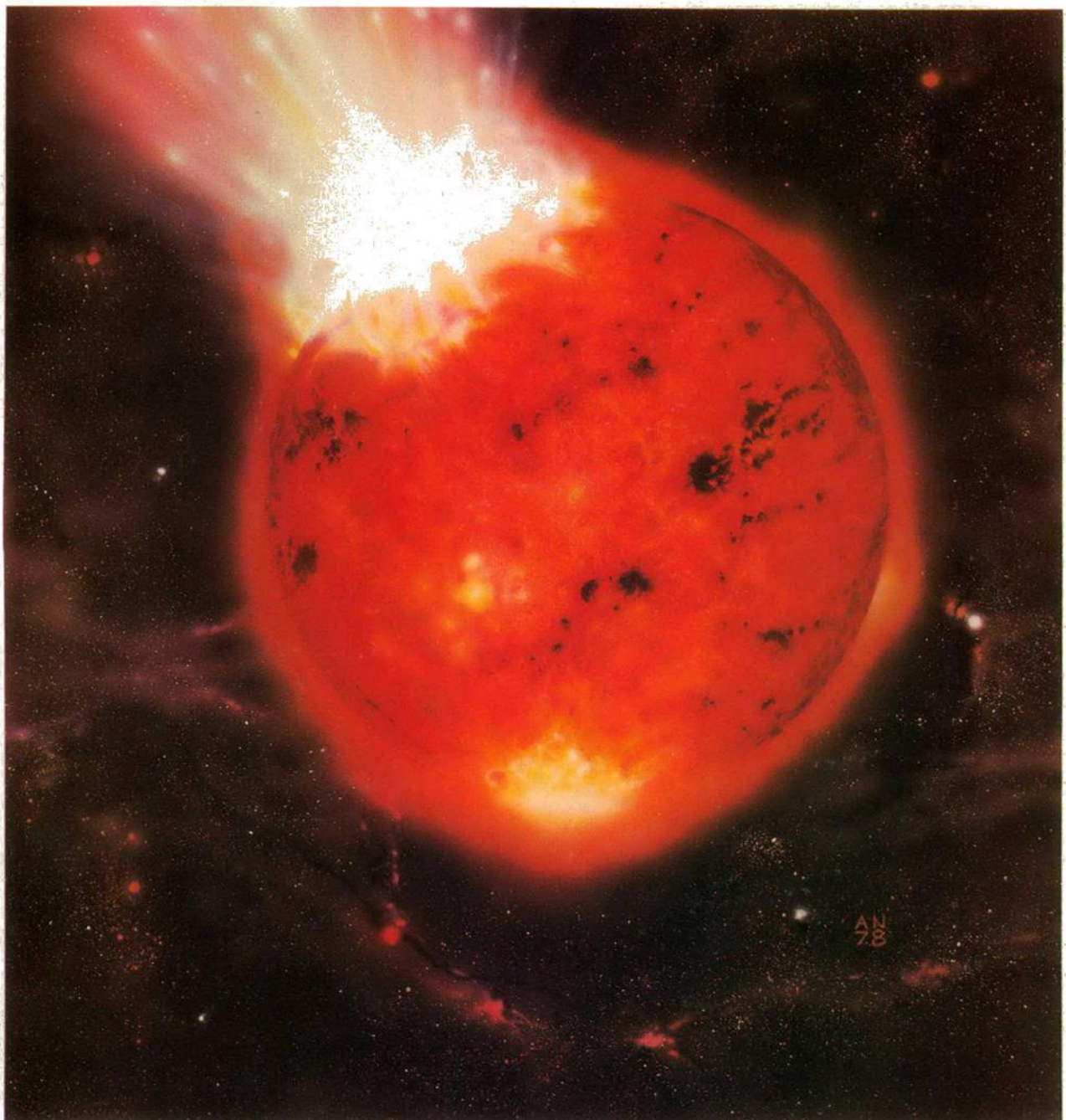


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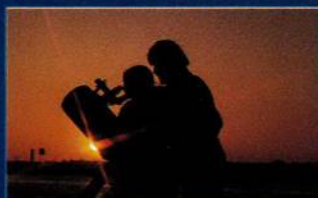
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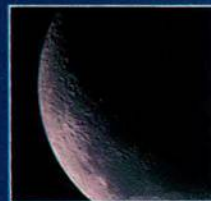
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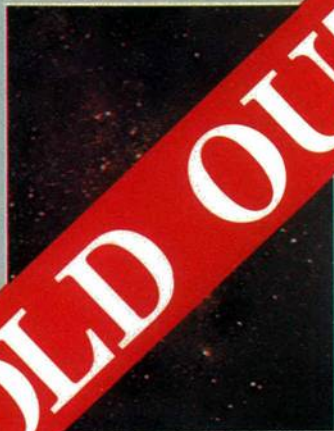
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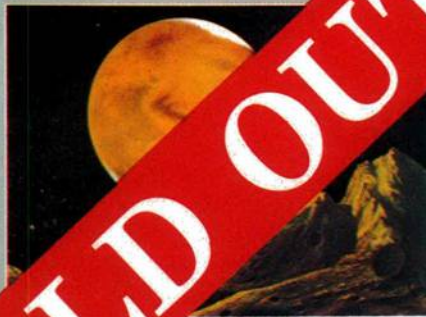
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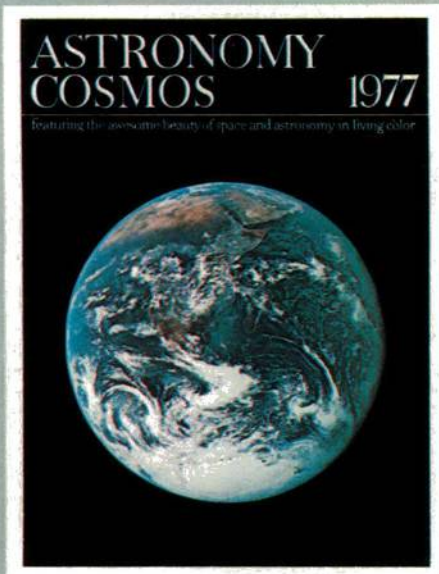
by Victor Costanzo, the red planet Mars and her satellite Deimos are set against a real stellar background. To the lower left of Mars is the Hyades, a star cluster in Taurus; at upper right is the constellation Aries. Varnished; suitable for framing. \$1.25 each.



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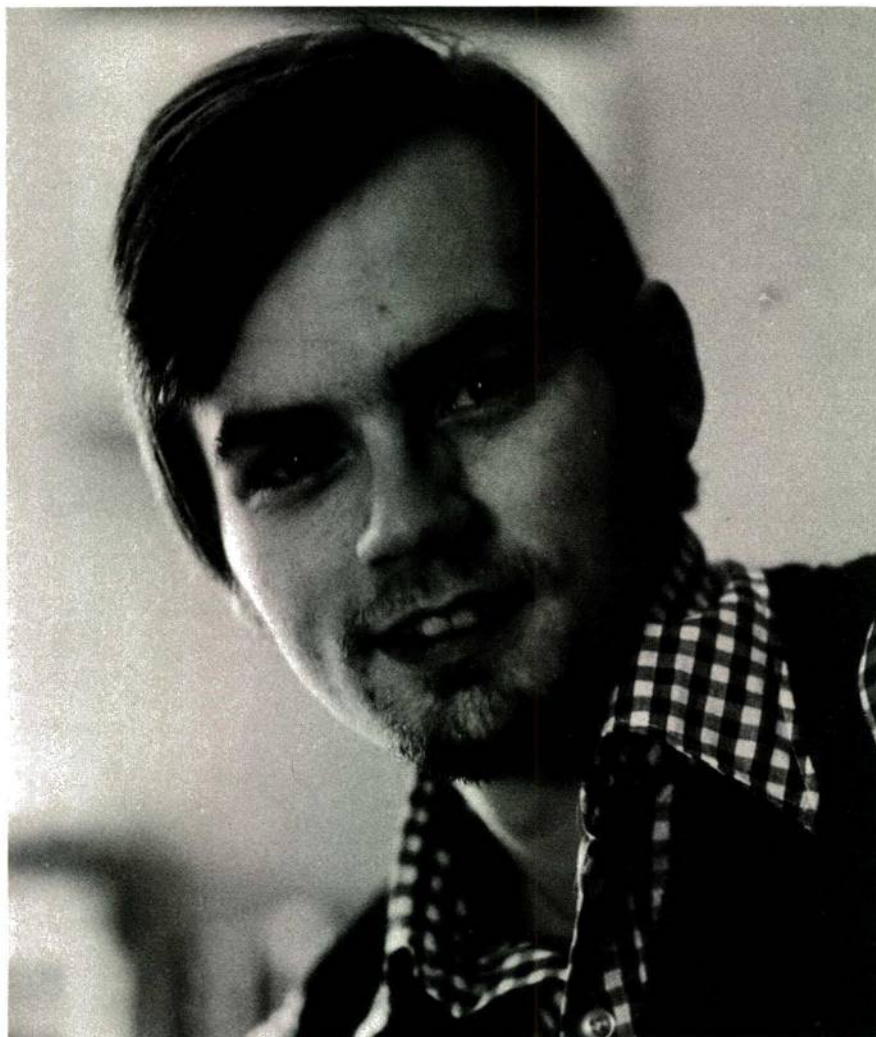
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Henry J. Phillips
May 8, 1952 – May 3, 1978

Henry J. Phillips, associate editor of *ASTRONOMY*, died on May 3, 1978 after a lengthy illness.

Following his graduation from Loyola University of Chicago in 1973, with a degree in English literature, Henry worked for *Encyclopaedia Britannica* as a copy editor. His interests in writing and cartooning continued to grow, and he developed a cartoon strip — “Welcome to

Willow Woods” — which was later produced (in collaboration with *Encyclopaedia Britannica*) in booklet form for use in a classroom reading series. A year later, Henry became associate editor of *PRISM Magazine* (published by the American Medical Association).

Because he had a congenital heart problem which greatly limited his physi-

cal activity, Henry became an avid reader and an accomplished musician.

While a young boy, Henry asked his older brother to take him out and show him the constellations. His brother — as big brothers will — said he would... but only after Henry had learned the constellations. Henry proceeded to do so — memorizing *all* the constellations in the northern and southern hemispheres!

His thorough knowledge of the heavens made observing with Henry a privilege too few people had. He could attract a crowd with his running commentary, and seemed to know every star in the sky as a personal friend. A fellow observer once described him as “a verbal atlas”.

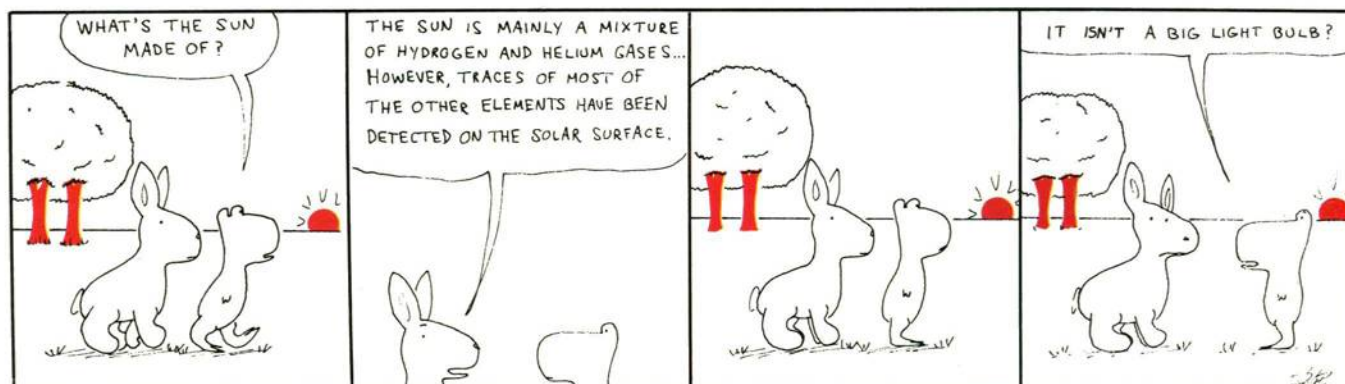
Henry joined *ASTRONOMY* in December 1975. Excited about an astronomy magazine whose goal was to bring astronomy to everybody, he felt responsible to his readers in everything he wrote.

Although much of Henry’s writing was not bylined, his distinctive style was evident throughout the magazine. His flair with words and natural ability to tell a story gave Star Dome readers many enjoyable moments. (In his spare time, Henry had started work on a book on constellation mythology.)

During deadlines, Henry often locked himself in his office, posting “Do Not Disturb” signs which promised dire consequences if disobeyed. He’d then plunge into the “serious” business of writing: Picture him typing 55 words per minute with one finger — while balancing a book on each knee and two more on his typewriter stand!

Henry developed the “Eye on the Sky” column (a mini-Sky Almanac) for the *Milwaukee Sentinel*. He was a member of the Milwaukee Astronomical Society and appeared as guest lecturer for them and other local groups.

Among other things, we’ll remember Henry for his love of music, and his crazy sense of humor which spawned such things as “anonymous” fan letters to staff members and, of course, “Welcome to Willow Woods”.



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Cover

Flaring violently, a tiny faint red dwarf star may put on an unexpected show every few days for billions of years. Imagine actually being there, watching from space, when a flare suddenly occurs. You might have a few minutes warning, and see a bit of unusual activity around one of the starspots; then suddenly an intense flare might grow brilliant until it outshines the red dwarf star 100 times over. In this issue, ASTRONOMY takes you to meet red dwarf stars and their sudden flares, and then explores the life history of galaxies: Are they here to stay? You'll learn the summer constellations, find out more about what's inside a telescope and, in Sky Almanac, find out what's going on in the sky for you to see. Artwork by Anne Norcia.

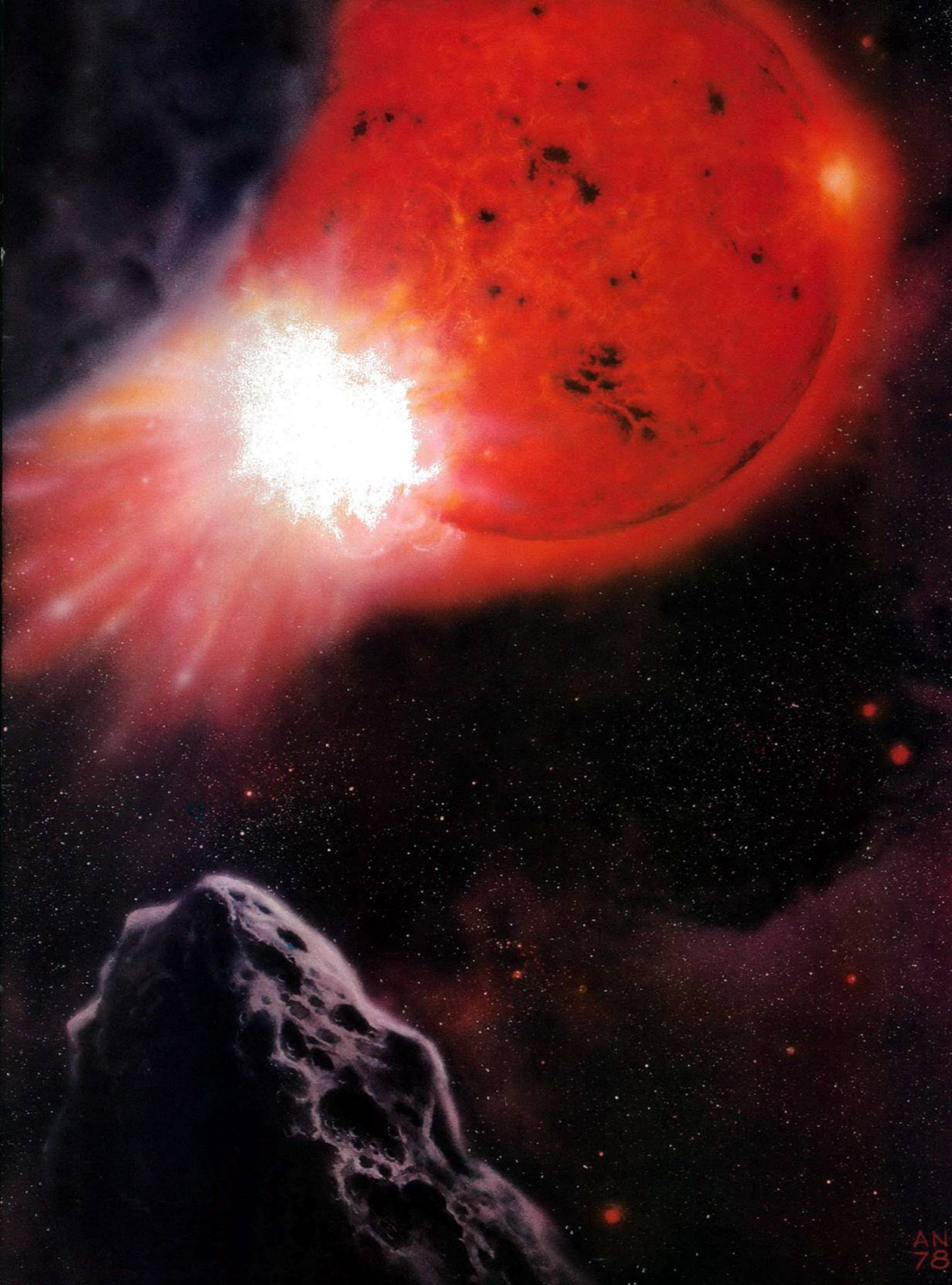
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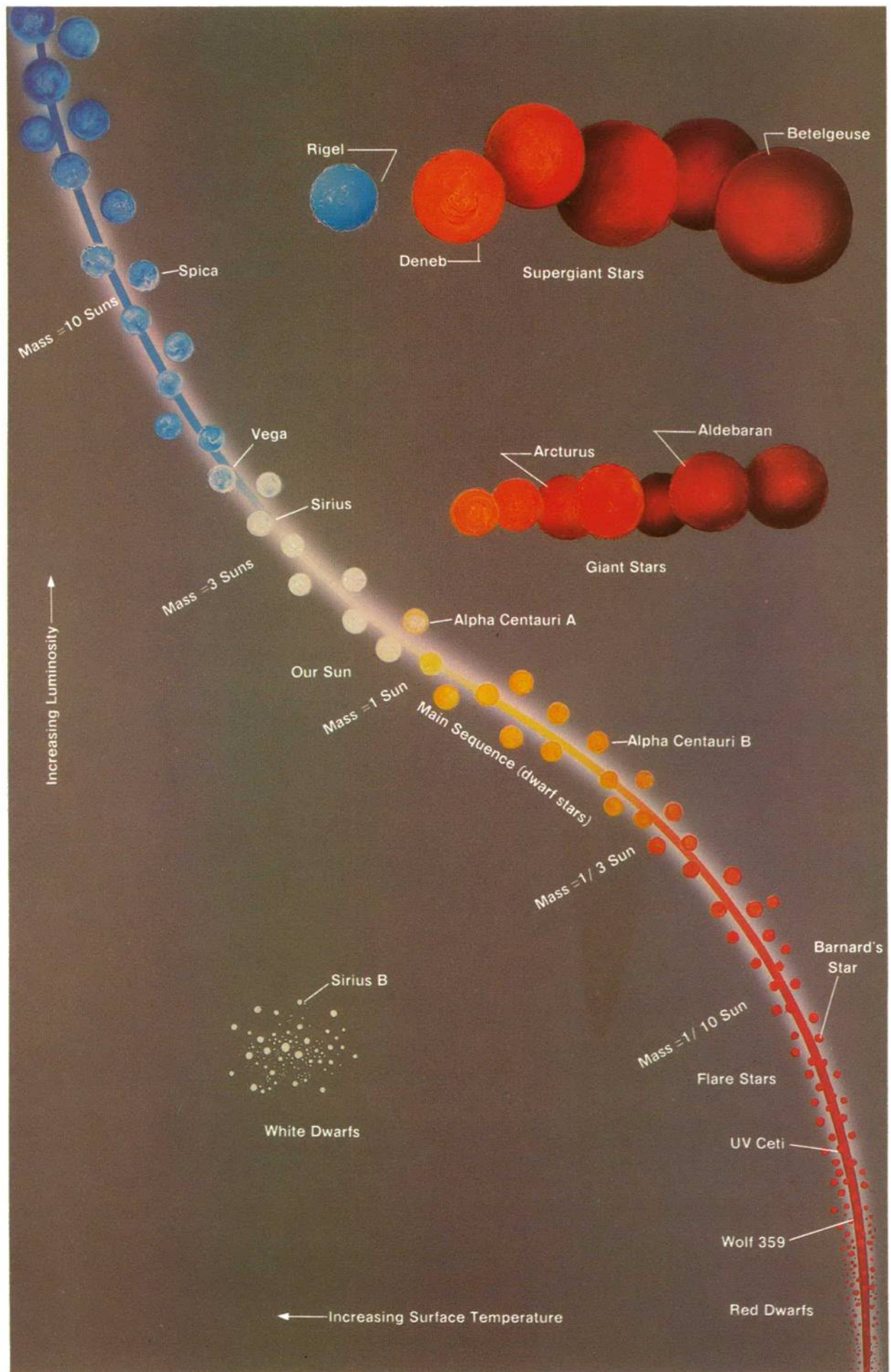




red dwarf stars

by
BILL JOHNSON





Deep in the back country, away from the light pollution of cities, a person can see infinity by looking up. Stars, especially those near the horizon which are invisible in the cities, are sharp, clear and plentiful, seeming to go on forever.

The naked human eye can see about 6,000 stars. Add to this the approximately one billion stars that come into focus if telescopes and photographs are used, and the sky seems a very crowded place.

Yet you see the youngest tenth of a universe.

Billions of years from now the night sky will be dark. Earth will be cold and dead, feebly illuminated by a sun which will have turned into a white dwarf star — a tiny, hot disk, too bright to look at directly but so small the total light Earth receives will be much less than at present. Overall it will seem as if the universe, a dark and forbidding place, is in the last stages of "running down".

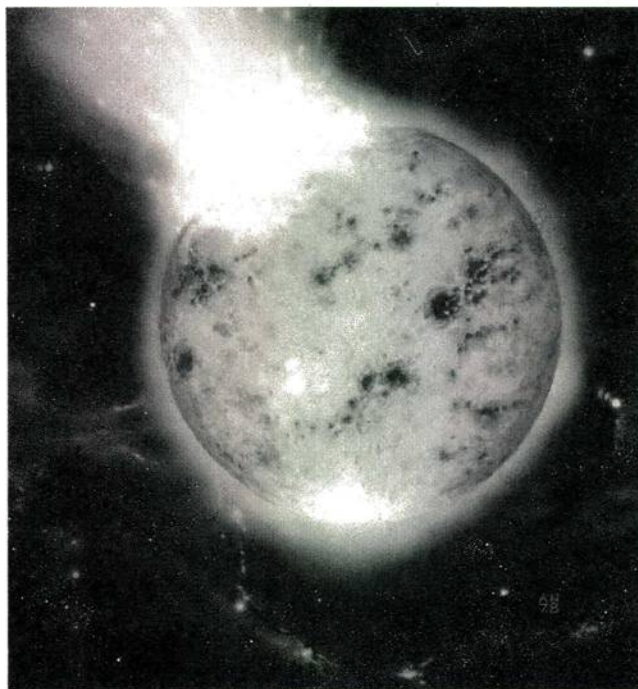
Interestingly, though, most of the stars (about 90 percent) which exist today will still exist, almost unchanged, in that remote future. The survivors will be the red dwarf stars, scattered throughout the sky. They are some of the most stable objects in the universe and, at the same time, some of the most unstable.

Red dwarf stars are born small, usually less than 1/3 the size of our sun. Their surface temperature is low, which gives them their distinctive ruddy color. They are the runts, made up of gas left over from the creation of giants and the more stable stars. Red dwarfs are the longest-lived stars in the sky. They'll be around long after all the more massive stars have burned out. They are very young for their kind and — even now — have barely started on their long journey.

The evolution of a star depends, basically, on its mass. It's a good rule of thumb that the greater the mass of a star, the hotter it will burn. ("Burn" is the word most often used by astronomers to describe complex nuclear reactions which produce energy, making the stars shine.) More mass causes greater pressure in the core of the star, and as pressure increases, so does temperature. Increased temperature means a star burns more hydrogen (the main component of most stars) more quickly, and this further raises the temperature of the stellar core.

Massive stars — those with several times the mass of our sun — are spendthrifts. Even with the vastly larger supply of hydrogen fuel they begin with, they'll exist only a few million years in their original state. They burst into life suddenly and hotly. Evolving quickly, they die when their fuel is exhausted —

Stars can be classed according to their luminosity (light output) and their spectral class, which tells their surface temperature. Our sun is a class G star, middling in light output, temperature and mass. Most of the bright stars in our sky are luminous main sequence stars like Spica, or brilliant giant or supergiant stars like Arcturus and Betelgeuse. Cool, faint and small, red dwarf stars are inconspicuous. What they lack in spectacle, though, they make up for in numbers: Over 3/4 the stars in our galaxy are red dwarfs. Diagram by Mark Paternostro.



sometimes with a bang that outshines an entire galaxy.

Stars with a lesser mass, like our sun, are more conservative. Their temperature rises slowly, over billions of years. Eventually, though, they deplete their supply of fuel and continue on their evolutionary path to become a white dwarf and finally a black dwarf star.

Red dwarfs begin with a vastly smaller supply of hydrogen compared to the giant stars and our sun. The pressure on the core of a red dwarf star is barely enough to ignite the hydrogen in the core. As the temperature rises inside, lack of sufficient mass to provide enough pressure prevents the spread of the ignition area. Though it starts with much less fuel, the red dwarf hoards its hydrogen and burns it frugally. Only after many, many billions of years, when most of its hydrogen has been burnt, will a red dwarf change. The lifetime of a red dwarf star should be much longer than that of any other star, but eventually even red dwarfs have to change. One of the ways some red dwarfs change is unique in its violence and frequency.

In 1948, a curious type of star was discovered. Typically, it was a red dwarf that would very abruptly brighten by several magnitudes. Outbursts were totally unpredictable. The rest of the time, the star would flicker, varying by only a few tenths magnitude. These odd specimens were named UV Ceti stars after the prototype UV Ceti in the constellation Cetus. There is no rhythm to the explosion's appearance, and it's impossible to predict when the next one will occur.

Approximately 100 nearby red dwarfs have been identified as flare stars. Since you can't detect the dim red dwarfs at more than a few light-years distance, astronomers can examine only the stars in the neighborhood of the sun. However, it would be extremely unusual if red dwarf flare stars were a phenomena which occurred only in our small, nearby section of the uni-

Why Are There So Many Red Dwarfs?

When astronomers count the stars, their goal — like that of a census taker — is to find out not only how many stars there are, but also how many stars of all the different types there are. Just counting the bright stars is not enough, for the brightest stars outshine the most common ones by a billion times. To take a fair sample, millions of stars must be checked, and only those stars inside a certain distance can be included in the count. When the numbers finally come in after tedious decades of work, red dwarf stars turn out to account for 75 percent of all stars near the sun. Stars like our sun account for a mere four percent of the stellar population, and bright stars like Sirius are only 1 in 200.

When stars are “born” from interstellar gas clouds, some process must favor the formation of small stars, yet it isn’t obvious what it is. When gas clouds begin to collapse, whether triggered by random perturbations in the gas or shock waves from supernovae, big clouds would seem to have the advantage — they certainly have the greatest gravitational forces. Somewhere along the line they must break up, however, whether it’s early while the collapsing gas is cold, or later when the gas is heating and beginning to glow. However and whenever they break up, and most of the fragments must be tiny — destined to become red dwarf stars.

verse. It’s safe to assume that red dwarf flare stars are very common and that our local space is typical. If this is true, then many of the red dwarfs in the universe, are wracked by violent explosions.

Flares occur when a portion of the gas deep inside a star, much hotter than the outside of the star, is brought to the surface. This gas is compressed and funneled to the surface in a matter of minutes by intense magnetic fields. Once outside the magnetic field, the gas rapidly expands and cools, but not before a stream of highly energized and ionized particles has been shot free of the star’s surface.

The power of flares varies according to the size of the star. Usually the smaller the star, the more spectacular its flare. Our own sun has had solar flares which disrupted short wave communications on Earth and would have made space travel extremely dangerous. The main difference between solar flares and red dwarf flares is the amount of energy released. Stellar flares have been recorded which were 10,000 times more powerful than any solar flare. Red dwarfs also flare far more often than our sun. Solar flares also emit radio waves. Flare stars do too: In fact, they were the first examples of individual stars (other than the sun) that were “seen” by radio telescopes.

There is no discernable pattern in the occurrence of stellar flares. These explosions occur more often and, in comparison to the size of their star, are more powerful than any other recurrent phenomena in existence. Recurrent novae also explode, but not as often as red dwarfs, and the reason they explode is different (see “Exploding Stars”, *ASTRONOMY*, February 1976 and “What Makes Novae Blow Up?”, *ASTRONOMY*, July 1977). Red dwarfs provide their own fuel and explode far more often. One star, II Tauri in the Hyades, had 14 separate flares in a little over nine hours! II Tauri is an extreme case, however; most don’t flare anywhere near that often.

We know red dwarf flares are a localized phenomenon because the temperature of the flares, about 27,000 degrees Fahrenheit (15,000 degrees Kelvin), has been determined from the spectrum of the flares.

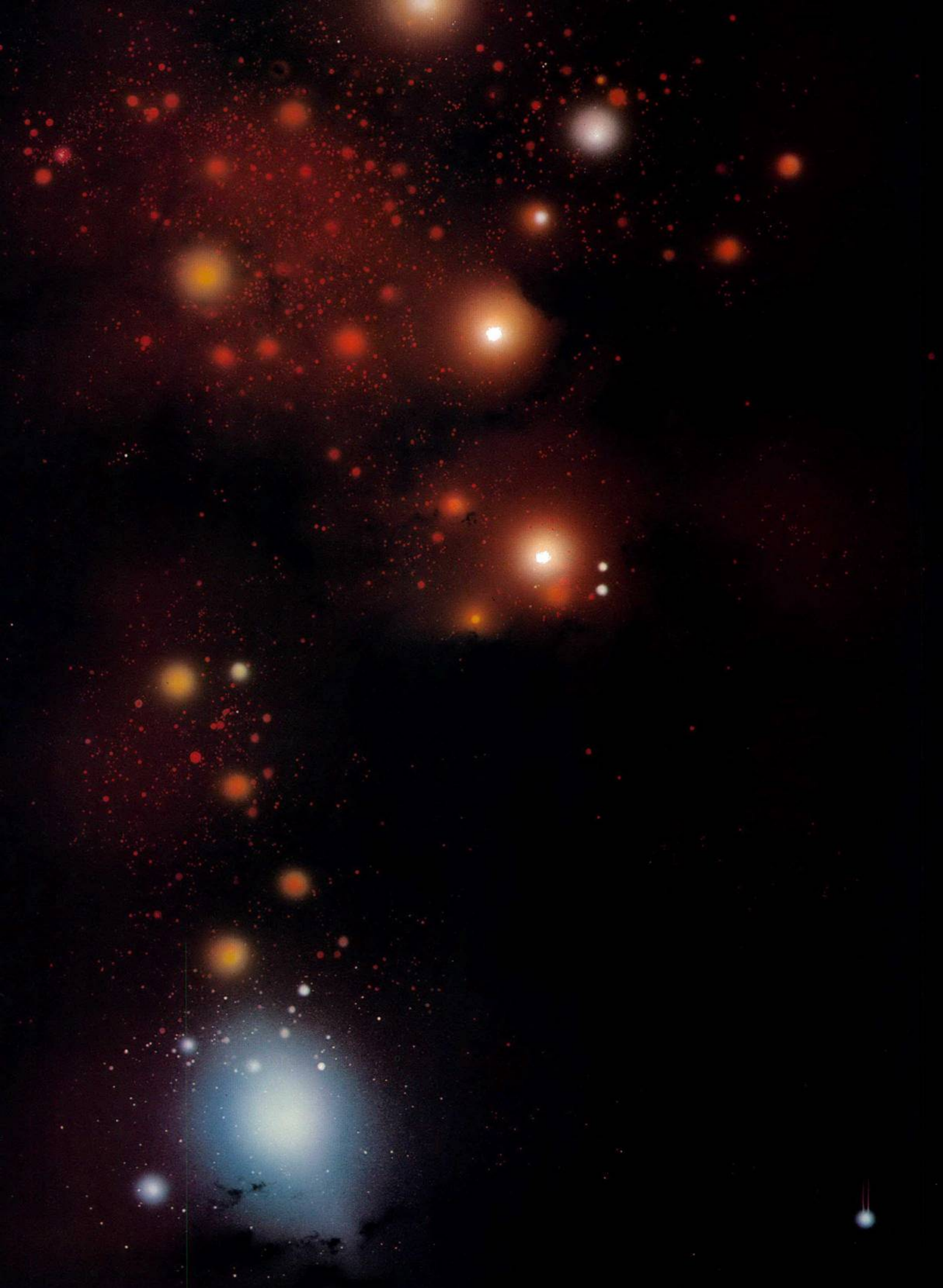
Scientist analyzed this data and decided that if the entire star had suddenly been raised to this temperature, there would have been a much greater change in the star’s apparent luminosity. Since the average red dwarf has a surface temperature of only 3,000 degrees Kelvin, the “hot spot on a cold star” theory developed.

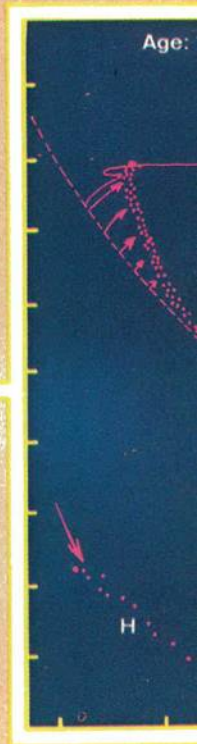
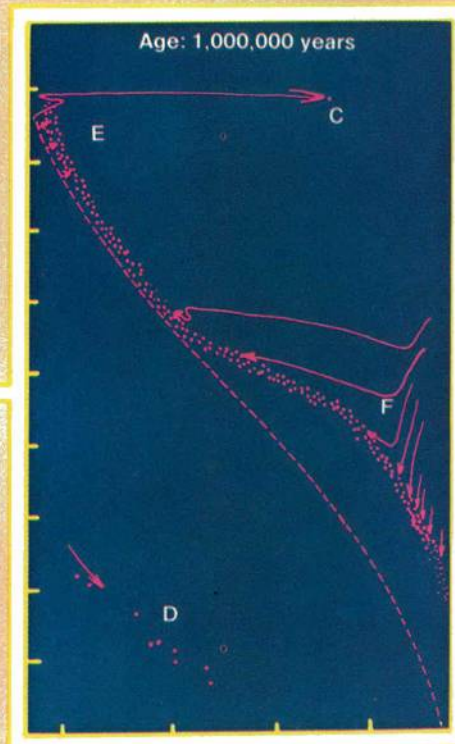
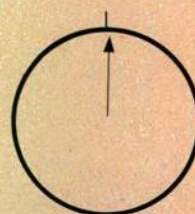
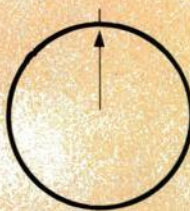
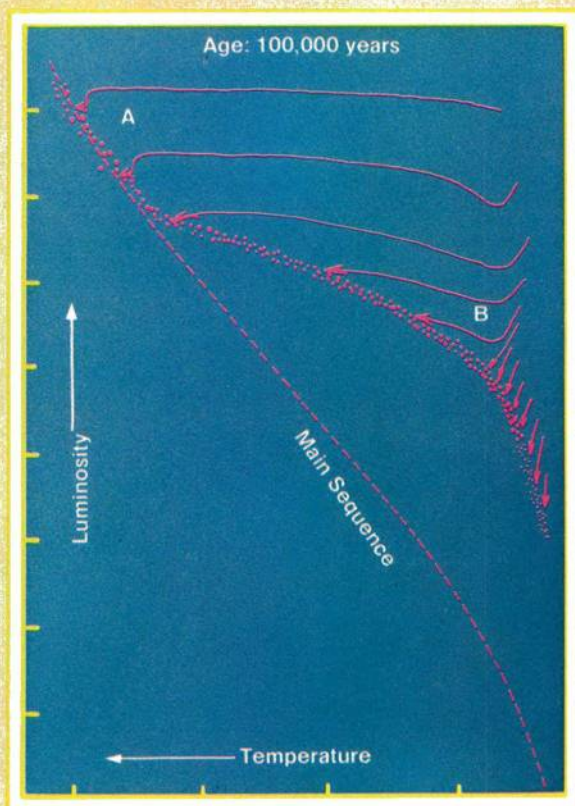
One model of a red dwarf flare star says the star can be compared to a gigantic onion with thousands of different layers. In the case of a flare star, the layers are shells of hydrogen with each of these shells rotating at a different speed from the shell above it and below it. These shells each have their own magnetic fields of various strengths which connect with the other shells. As the shells rotate at their different speeds, they stretch and alter the other fields, creating anomalous fields inside the star. As these magnetic fields interact in the interior of the star, they eventually have an effect on the magnetic field of the surface of the star.

If the theory is correct, then the surface of a red dwarf star has a twisted magnetic field. Throughout the main field lie scattered areas of unusually great strength, so that some areas of the star are more highly ionized than others. As the unusual areas spread and the differences become greater, the star’s magnetic equilibrium can be stretched to the breaking point.

When the magnetic fields finally collapse, chaos erupts. Parts of the star’s interior are brought to the surface. In some ways, it works like the “Old Faithful” geyser. Very hot, highly pressurized water, which has been trapped under rock, spurts to the surface in a violent eruption. After the pressure has been released, everything goes back to normal — and then the process begins again.

Imagine for a moment that you could see *all* the stars just as they’re made in a cosmic gas cloud. Coming off the stellar assembly line, red dwarfs would dominate any stellar population census you might try. But when it comes to shining across vast interstellar distances, red dwarfs are modest to the point of invisibility! Radiating only 1/10,000 as much light as our sun on the average, even those red dwarfs closest to Earth are too faint to be seen without telescopic aid. Artwork by Mark Paternostro.





Imagine that you watched a cluster of stars form, age, evolve, and die away — from beginning to end. Which stars would live the longest, which the shortest, and which would lead the most exciting lives? Look: The grand scenario is about to begin. . . .

As a great cloud of interstellar gas collapses and fragments into star sized pieces, we'll start the clock. Its face reads from zero to 10 billion years — the lifetime of our sun. It'll be a while before we see any movement of its pointer, for that's a very long time. We'll watch a graph showing each star's luminosity plotted against its surface temperature — the familiar Hertzsprung-Russell diagram — undoubtedly one of the best ways to watch stars change!

In a mere 100,000 years, the massive giant stars race from warm gas clouds to brilliant stellar beacons (A), shining 100,000 times brighter than our sun and burning with a blue-white heat. They lie on the main sequence — meaning that they are burning hydrogen in their cores. Less massive stars (B) are still shining by the simple heat of contraction as they contract toward the main sequence.

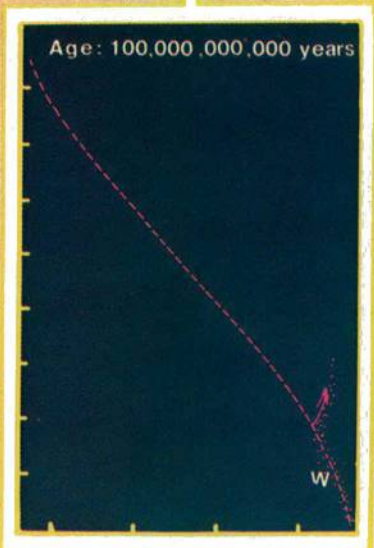
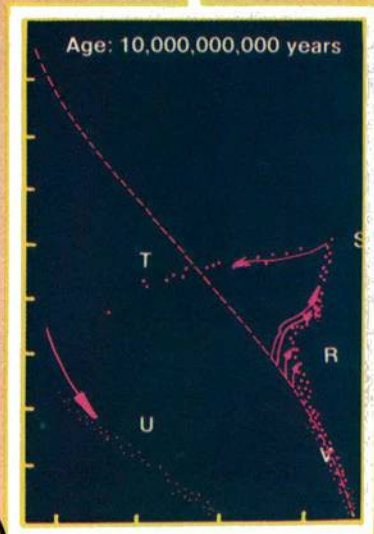
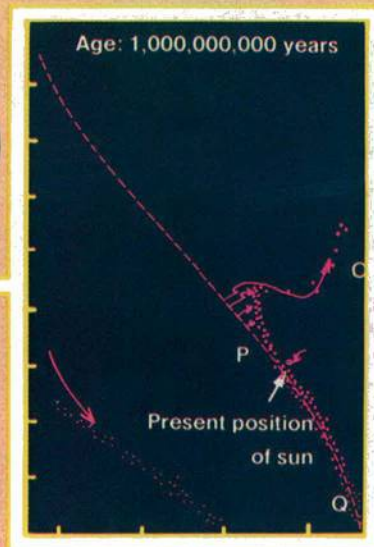
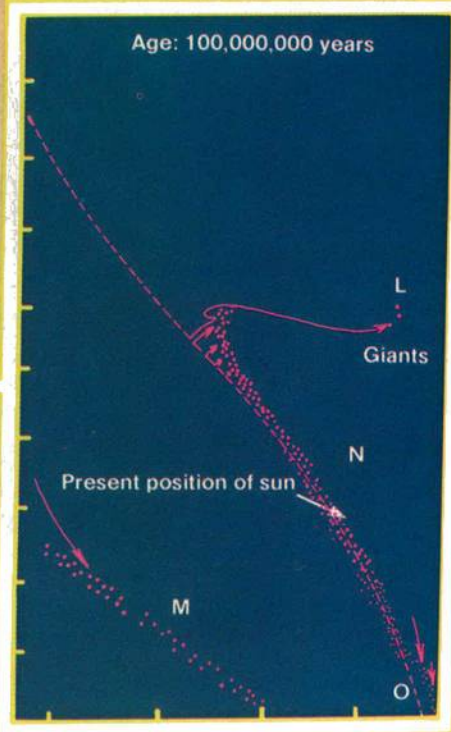
After a short million years, the most massive stars have already exhausted their hydrogen fuel. They expand, cool and burn helium and heavier elements (C), then supernova and leave white dwarfs and neutron stars (D) behind like cooling,

fading cinders. Meanwhile, slightly less massive stars (E) are just leaving the main sequence, while middleweight stars (F) continue to move toward the main sequence.

Ten million years after our cluster began, more and more of the massive stars have burned their fuel (G), exploded and faded away (H). Most of the middleweight stars have reached the main sequence, but solarweight stars (I) are still cooling and contracting. The still-forming nebulae that will become red dwarfs (K) still have a long way to go.

One hundred million years is long by human standards, but short on a cosmic timescale. The fast-paced middleweight stars have now exhausted their fuel, and move into the giant regime (L) to burn helium as fuel and expand into giant stars. When they finally run out of all fuel, they will throw off a shell of gas — perhaps many times — and then settle into white dwarf obscurity (M). Solarmass stars (N) have reached the main sequence and are burning hydrogen in their cores. Note the clock has just begun to move — the sun would now have passed the first one percent of its lifetime.

A cluster one billion years old has many red giant stars burning helium and heavier elements (O) on the red giant sequence. The red giants are now the brightest lights in the cluster;

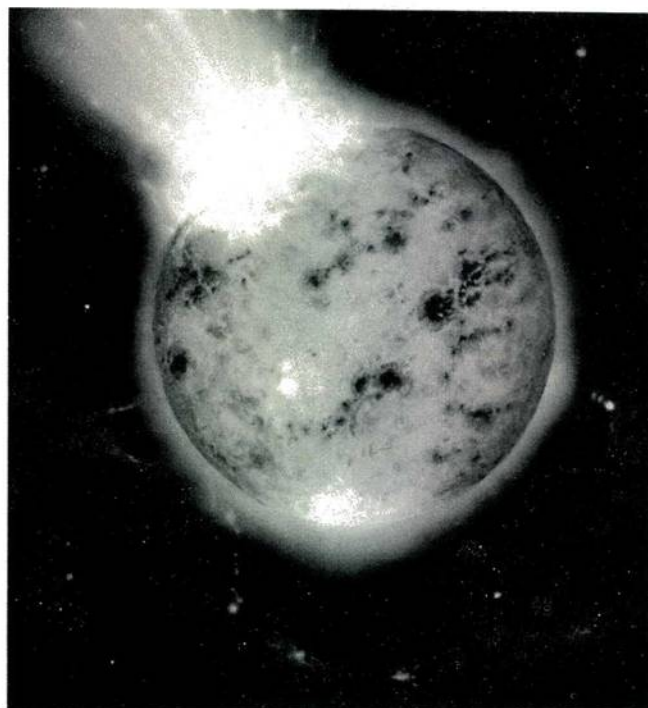
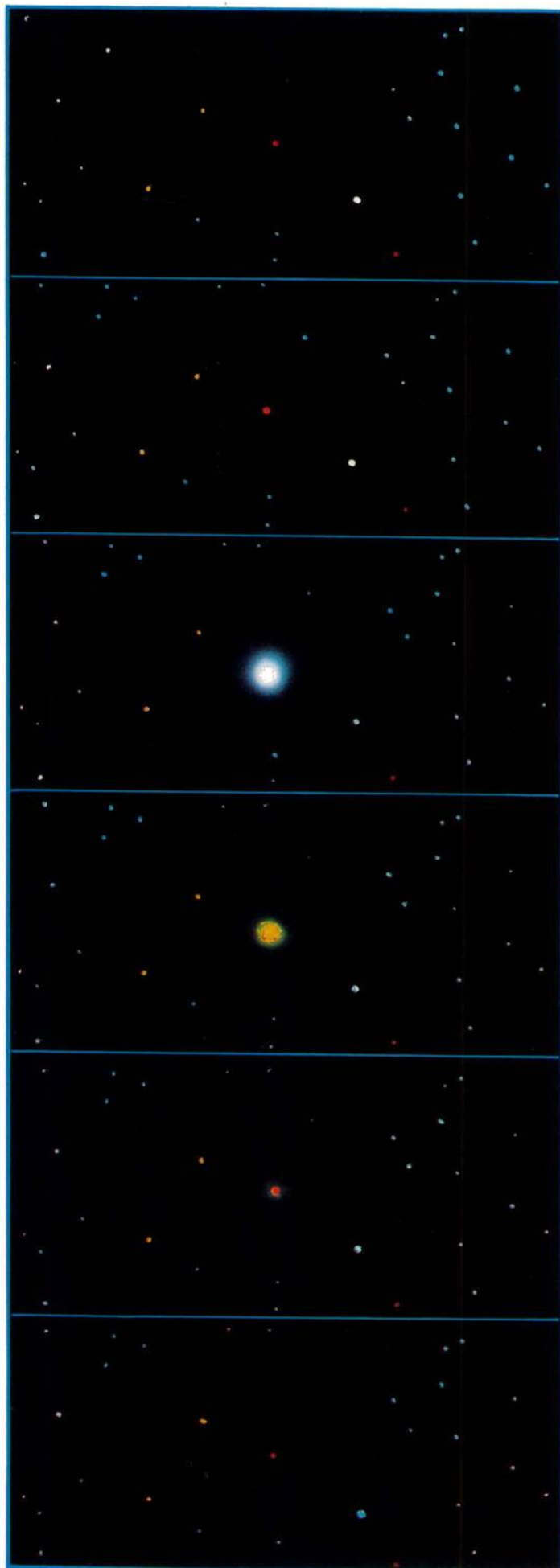


gone are the last of the bright blue stars. Stars like our sun (P) may look forward to billions and billions of peaceful, stable hydrogen burning years. The clock has begun to move as we take bigger and bigger steps across time. Now the red dwarfs have at last begun their lives, burning their small store of fuel in a very frugal manner, guaranteeing near immortality, as stars go.

Ten billion years — the clock is finished. Our sun, its hydrogen gone, is heating up, expanding, and going the way of giant-hood (S). The less massive giants don't end in a bang — they move in a leisurely fashion across the horizontal branch (T) pulsating, puffing out shells, and finally shrinking, cooling (U) and dying. The red dwarfs have just begun life (V) with a small fraction of their fuel expended, their snail-pace at last an asset.

We can hardly look 100 billion years into the future without some misgivings: Nothing in the universe is that old! We don't know what will happen to these stars as they burn the last of their hydrogen. But we do know that there will still be red dwarfs (W) plodding along — the survivors, who outlasted everything else.

Calculations and diagrams by Michael Seeds, Franklin and Marshall College.



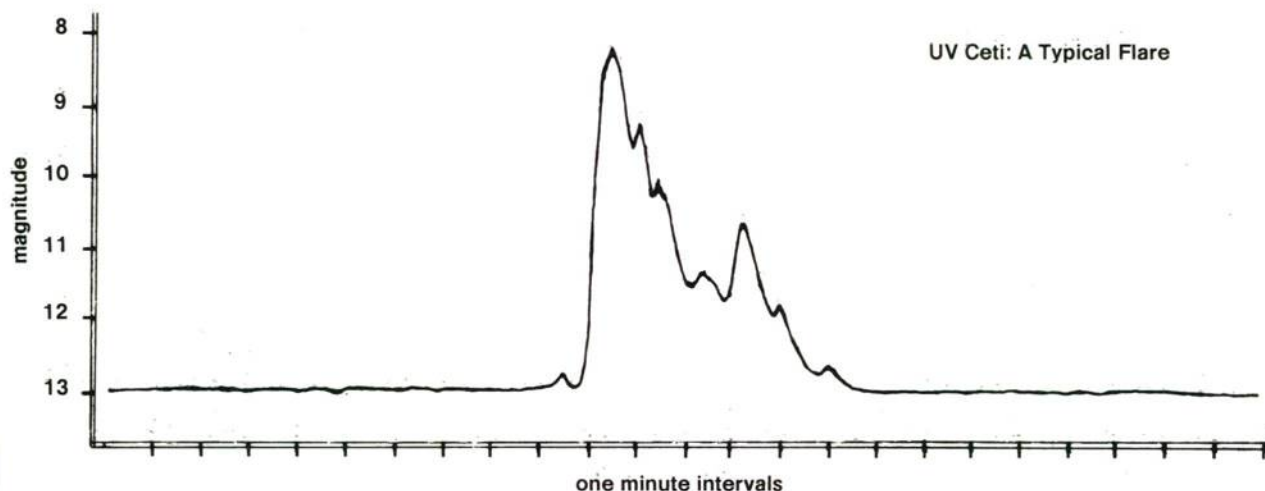
Several different elements combine to form what is called the *flare event*. In the typical flare event there is first the slow phase, followed by a preliminary flare, and then the main flare.

During the slow phase, there is a localized increase in the star's radiation output, caused by the injection of a large amount of energy into a small area of the star. However, this injection is neither large enough nor done so quickly that it cannot dissipate without an explosion. Occasionally, at this point, the flare may subside without any further energy release.

In the typical event, next comes the preliminary flare which, on a graph, looks like a small bump on the steady rise of the slow phase. The precursor flare is a small explosion which quickly subsides. It may act as a trigger mechanism, or it may just be a side effect of the entire flare process.

The *spike flare* (what is generally referred to as "the flare",) usually occurs a few seconds after the precursor. During the spike flare, many times more energy comes from the flare than comes from the rest of the star. At peak, then, the flare outshines the star. At this point in the slow phase, so much energy is injected into a small area that a shock wave starts and helps to continue the flare. Then, in a matter of a few minutes at most, the energy production drops rapidly — almost back to the original level — and the spike flare is over. In the average flare, the slow phase

Flare stars erupt with sudden dramatic violence. Minute by minute, you can watch the progress of an intense flare. After hovering at the edge of visibility in a large telescope for hours—even days — a flare begins virtually without warning. Within a minute the star has attained almost naked eye visibility. Fading nearly as fast as it flared, the flare event is over almost before it happens. Between flares, you might have to wait hours, days or even weeks before another event. Artwork by Mark Paternostro.



UV Ceti: Prototype

The 13th magnitude red dwarf star UV Ceti is the prototype flare star. It lies only eight light-years from the solar system, yet can be seen only with difficulty in a six inch telescope. (For comparison, the brightest star in the sky, Sirius, lies nine light-years from us.) UV Ceti varies slightly in brightness with a period of around 33 days. On the average, flares occur every 40 to 60 minutes and last for five minutes. Average flares outshine the star a few hundred times, the biggest by a few thousand times.

At peak brightness during a large flare, UV Ceti reaches sixth or seventh magnitude. Lots of red dwarfs other than UV

Ceti have flares also. The more luminous the star is though, the slower, larger, less frequent and longer lasting the flares are. YZ Canis Minoris and AD Leonis, for example, produce an average of three or four flares per day, each lasting 10 minutes.

The number of UV Ceti stars is very large, but the probability of finding them is quite small because they are faint and the flares are short-lived. Nonetheless, if you were to watch a field of 2,000 ordinary stars with a very large telescope (so that you could see stars as faint as 20th magnitude), you would see, on the average, one flare every 90 minutes!

energy production decreases until the total energy production of the star comes back to normal after a few minutes.

Much of the energy released by a flare star is in the ultraviolet and radio ranges. Very little of it — perhaps one percent or so — is in the form of visual light. Nonetheless, the visual magnitude of flare stars increases an enormous amount during a flare — sometimes as much as six magnitudes.

The bigger the flare, the longer it will last. While most red dwarf flare events last only about a minute or so, a large flare can last as long as an hour. The largest flares have been recorded on the most luminous red dwarf stars, and the more often a star flares, the less powerful its flares tend to be. The time between flares seems to follow no pattern, but usually averages at least a few hours. Most flare stars flare about three or four times a week, but we can only see half the star since one side remains hidden from our sight.

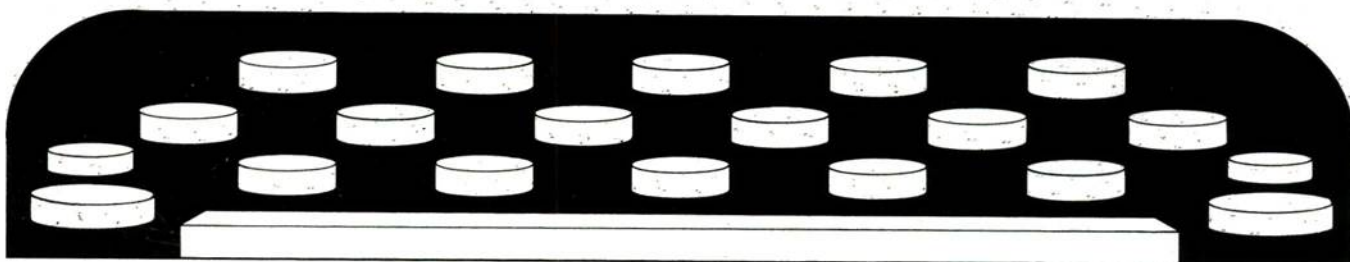
Flares happen on our sun near the sunspots, where local magnetic fields are intense. Some scien-

tists have proposed a theory to explain red dwarf flares using starspots (gigantic sunspots on the surface of red dwarf stars). Sunspots only last a week or so, but starspots could last for months or even years. Some scientists thought that as much as 1/5 the dwarf's surface could be starspotted.

As the red dwarf stars slowly age, they will probably become more stable. The loss of material from an individual flare is very little, but over the multi-billion year lifespan of a red dwarf star, a great deal of material eventually drifts off. Red dwarfs will age, mature and eventually become quiet.

But the timescale for red dwarfs is slow. By the time they reach a stable point where they do not explode every few hours or days, they may well be the only stars left in a very dark universe. 🌑

Bill Johnson is a science writer specializing in physics and astronomy. He currently works for a large data processing firm as a technical writer — "conveying", in his own words, "very technical concepts in clear language".



IN FOCUS

Ooops!

April 1978, pages 33-34 — in *Equipment Atlas*, the plano surface of both lenses face outward, not toward the incoming light as stated in the text. While the drawing is correct, the field lens and eye lens labels are reversed. On page 33, referring to the surface of the secondary mirror, the text reads, "the quality of its surface is not important." It should read, "the quality of its surface is not unimportant." We apologize for any confusion these errors may have created.

May 1978 page 62 — an *Astro-News* "brief" states that a canyon discovered in the south Atlantic Ocean measured 420 miles (700km) deep. Boy, were we wrong! The canyon actually measures 1.8 to 2.4 miles (3 to 4km) deep, 18 miles (30km) wide and 420 miles (700km) long.

Sir / I want to build an RFT to mount on top of my eight inch Cassegrain tube. I want to maintain the same eyepiece location for both units, so that rules out the Newtonian form of RFT. That brings us to the refractor. The only air-spaced RFT refractor objective I can find is the Jaegers six inch f/5, 30 inch focal length coated one. It would appear to be the answer to my needs, but at \$345 I'd like an expert opinion. I've heard tales of horrendous color fringing, coma, and that RFT refractors are useless for photography — but it's always been secondhand advice, never from the man who owns one. I want to use it visually and photographically on deep sky objects. I would hope not to have to cut the lens' speed with filters (for black and white photography) just to cut down on chromatic aberration to obtain a sharp image.

If you think the refractor isn't the answer, what would you suggest? Would a surplus 12 inch f/2.5 Aero-Ektar be usable both photographically and visually? I have my doubts about Ritchey-Chrétiens, because of the huge secondaries. The only other form I can think of would be a short focus Mak-sutov of some sort.

How prohibitive would the cost be for

a three element RFT refractor objective of four, five or six inches diameter?

DAVE HOWARD
Ocean Beach, Calif.

Mr. Howard / For visual observations the Jaegers five inch objective is outstanding for so fast a lens; however, at that speed, f/5, no simple achromatic objective will give excellent color free images. I have looked through two such lenses mounted and exhibited at telescope meetings I attended and found the views enjoyable. However, it isn't practical to apply a very high power on such a lens because then the secondary color does become apparent.

Unfortunately the universal telescope has not been invented, so you require two instruments for the work you mention. For the photography, the 12 inch f/2.5 Aero-Ektar would be better than the achromatic lens. Many of these lenses were designed for working in the near infrared and don't give as small an image as one designed to work in the blue region of the spectrum. The seven inch focus f/2.5 Ektar is a better astrolens. Used on a 2-1/4 inch square film and stopped down to f/4, it is used by some professionals in their work.

Although you want to have the eyepiece of the Cassegrainian and RFT in the same location, this is not possible if you use the Newtonian form. But there's a solution that has been applied by many observers: Mount the RFT on the opposite end of the declination axis of a German mounting! Not only does the Newtonian act as a counterweight, but it also keeps the eyepiece position low relative to the ground.

The cost of a special f/5 highly corrected lens is outside the pocketbook of the average person. I saw one in 1942 that was a 10 inch f/10 made by Perkin-Elmer Corp. for an observatory in Florida. The cost then was \$25,000! With today's inflation, I would hate to even suggest a price. — Robert E. Cox

Sir / I read "What's Inside Your Telescope?" in the March 1978 issue and enjoyed it very much. I am in the process of building an eight inch reflector. The tube will be an open type made of pine wood, and I plan to build an English yoke equatorial mount for the scope.

The only problem I've come across so far is how to determine the proper size secondary mirror. There are several

sizes available but I don't know which size I should use. I'd appreciate your help with this problem.

TIM LINDER
Landrum, S.C.

Mr. Linder / For a standard size telescope — in your case an eight inch aperture, probably of around 64 inches focal length — the size of your diagonal can be close to 1.5 inches minor axis (the long axis will be about 2.125 inches).

Too much attention is given to diagonal size, with many complex formulas used to determine its dimensions that really only apply to a case for advanced observing with a specific project in mind. The 1.5 inch size will provide a full field of illumination equal to the moon's diameter, and will more than adequately cover the field of good definition. This same diagonal size will be acceptable for 54 to 80 inch focus instruments.

Size determination of the diagonal is quite simple. First find the diameter of the full field of illumination (the moon's diameter); then divide the focal length of the mirror by 114.6. For your mirror, this is $64/114.6 = 0.558$ inch. Now, by simple proportion, find the size of the light cone at the intercept distance of the diagonal inside the focus of the mirror. Generally this is equal to the semidiameter of the mirror, plus one inch tube clearance, plus two or three inches thrown outside the tube for working room. For your instrument, let's use seven inches as the intercept distance. To find the desired size, multiply the mirror diameter by the intercept distance and divide by the focal length of the mirror: $(8 \times 7)/64 = 0.875$ inch. This, added to the selected field of illumination, is the diagonal size: $0.588 + 0.875 = 1.433$ inch! As this is not a standard size, the next larger figure is a 1.5 inch or 1.52 inch diagonal.

As pointed out in the April issue, the final performance of an instrument is determined by the combination of the correction on the two mirrors, primary and diagonal. Ideally they should be at least 1/8 wave correction on each surface. If better, with conditions of exceptional seeing, the telescope will perform outstandingly. — Robert E. Cox

Sir / When I moved into downtown New Haven, Conn. to work for an alternative newspaper, I assumed skywatching would be hopeless. But our top floor apartment had a 3x3 foot plastic bubble

skylight, which led me to try the view through it with 7x50 binoculars. My successes from then on, I believe, tell a great deal about what is and is not important for successful observing.

The conditions through the bubble (to begin with) were poor. The city skyglow was bright, streetlights prevented full night vision, and the bubble was not of optical quality. In addition, a film of pollution always coated its outer surface; if I washed it off, the first rain washed a new layer right back.

For ease of observing, however, the bubble was marvelous. Any time in the evening I could just pick up binoculars, cut the lights and get up on a stool to lean comfortably with my head inside the bubble. Skywatching in indoor warmth was an entirely new experience. And with a pillow to rest against and black cloth draped to minimize lights and reflections, the situation was much improved. I fixed up ledges to hold star charts, notepaper, a red flashlight and pencils. The bubble itself provided a vital necessity for binoculars: something rock solid to hold them against in all positions.

Star images were never perfect, but they were there all right, and that's what matters. I was surprised to find that even under these conditions the binoculars' limiting magnitude was as faint as 8.6.

The indoor comfort allowed me to take complete, careful advantage of this observing range. Freedom from cold meant I could concentrate on the faintest objects even in winter, and there was no wind to blow charts and notes. It was extremely satisfying to study, for instance, the shoals of stars around Xi and Nu Orionis in shirtsleeves while a 12 degree December wind whistled past just a few inches all around!

Relaxation and time for paperwork actually made my observing more productive than it had been with a six inch reflector under better skies. Through the bubble I identified scores of variable stars and steadily followed the progress of many — the seasons-long emergence into visibility of S Canis Minoris, the monthly pulses of T Monocerotis, the hourly changes during eclipses of RZ Cassiopeiae. I followed asteroids and drew maps plotting their looping paths, searched for dozens of clusters and examined many binocular binaries. I located such curiosities as Plaskett's star in Monoceros (the most massive star known — a spectroscopic binary with about 70 solar masses for each component), and Lalande 21185 in Ursa Major, the fourth closest star to the sun and, at magnitude 7.5, one of the very few red dwarfs visible in binoculars.

I started off using Norton's *Star Atlas* with the *Skalnate Pleso Atlas Catalog* as a reference book. I later used the excellent *Skalnate Pleso* sky maps.

When I ordered the catalog I was a bit overwhelmed at first by its 350 pages of dense tables of numbers, but it made the maps come alive — each faint star is an individual with its own distance, type and often binary or multiple companions. I drew maps of small areas of the sky with all these characteristics noted for stars, for inspection at night.

Doing this brought new perspectives to familiar starscapes. The top stars of Orion's club, Chi-1 and Chi-2, look nearly identical — both magnitude 4.7. Chi-1 is slightly off-white; according to the catalog it is a mild, nearly solar type F9 dwarf just 31 light-years away. Chi-2 turned out to be a blue supergiant 4,000 light-years away and about 40,000 times more luminous — a huge, distant searchlight next to Chi-1's nearby candle flame! It was simply impossible to visualize the difference between the two while looking at them in the same field of view.

Elsewhere, I drew up a map of all the stars detectable in Orion's sword region and found I could match it with photos of the Orion nebula and its stars. The New Haven skyglow wiped out all but the brightest part of the nebula itself, but around it I was able to identify the newborn variables NU, KX and V359 Orionis.

The lesson of this? A beginner's success with astronomy does not depend on big, expensive equipment or good skies, but rather on 1) the ease and practicality of observing, 2) good charts and reference catalogs and a willingness to do lots of desk work with them beforehand, and 3) a willingness to take good notes while observing.

There's no reason to invest in a telescope before you're familiar with the night sky and what observing is really like. Contrary to some advertising claims, the "splendors of the heavens" are very unimpressive in any smaller telescope (with the exception of the moon, Saturn and a few other showy objects). The satisfaction comes in detecting them at all, and in knowing what to look for. Careful binocular observing is good preparation for this, even under the worst city skies.

ALAN M. MacROBERT
New Haven, Conn.

Mr. MacRobert / Our sincere thanks for your account of observing through a "bubble".

Sir / I've been interested in astronomy since the eighth grade and my enthusiasm is still there. I found out early that most books stress telescope aperture over and over. The poor novice must feel he's got to have a large observatory in his backyard with at least a 12 inch scope, or he might as well quit. This is where I object.

It's time for owners of small to med-

ium sized instruments to stand up and be counted! I started out with a 3 inch, moved to a 4-1/4 inch and finally a 6 inch reflector. I've had — and expect to have — many exciting hours exploring the wonders of the heavens. The problem I faced was that the books I read all started out discussing the three inch refractor or six inch reflector in the introductory chapters, but later as the chapters became more specific about observing, remarks about "minimum apertures necessary" soon surpassed the small telescope range.

Aperture is stressed by most authors above and beyond all other things. At this point in most books, the haunting term "serious and/or useful work" makes its appearance. The poor observer with a small telescope feels "useless".

I don't begrudge those who have large aperture scopes looking for faint details visible only in their large aperture instruments. I salute those who make transit timings of Jupiter's marvelous cloud belts. I'd love to discover a new dome on the moon's surface myself, and who could but admire those dedicated observers training their telescopes upon distant suns to keep track of variations in brightness?

But I take exception to those who would term only this type of work as "useful" or "serious". If that's the case, then let's hear it for *useless* observations! True, smaller telescopes gather less light, but an optically excellent small telescope will show more detail on the moon, planets, globular clusters, open clusters, nebulae, galaxies, double stars and multiple stars than the average observer will ever have time to see! Too often I fear people who begin with a small telescope get "large aperture fever" and end up with a white elephant too large to use comfortably. Eventually the big telescope is stored away — unused! This is especially true if, as in my case, they must take their telescope away from city lights to observe. True portability and ease of use is found only in the small to medium sized aperture range.

But what constitutes usefulness or serious viewing? Since the Lunar Orbiter series, few persons observe the moon except as a showpiece to impress friends, since there's no "useful" work to do.

The point is that even though a picture taken by a spacecraft shows more detail than my small telescope can, to see it for myself far exceeds any photograph. Would you settle for looking at a photograph of a Van Gogh or a Rembrandt if you could see them in person? Would you turn down a trip to Stonehenge because there's a book in your local library with photographs of it? How about settling for slides of the Grand Canyon taken by a professional photographer instead of seeing it for your-

self? Seeing these magnificent sights with your own eyes is what counts.

So I say hurray for the stargazer who ignores talk that his scope is not large enough. Let him continue to observe the mysteries and wonders of the universe with a small telescope!

JAMES H. PHILLIPS, M.D.
Charleston, S.C.

Sir / Would you explain, in detail, why one generally may distinguish a planet from a star by the fact that the former does not "twinkle" in the night sky? The explanation most often given alludes to the passage of starlight through layers of Earth's atmosphere that may have different temperatures and movements; however, this seems implausible because the light from planets likewise traverses the same atmospheric conditions, and planets normally do not twinkle.

ANDREW J. SMATKO, M.D.
Santa Monica, Calif.

Dr. Smatko / The planets don't twinkle as the stars do because light from a planet comes from a large disk. Atmospheric bending of the light from a star is likely to remove all the light from the path reaching your eye one moment, and the next moment bend more light into it. Thus a star twinkles. Because the planet is an extended object, light from part of the disk may be bent away, while light from the rest of the disk continues to reach your

eye. Though a planet does twinkle some (especially when the disk is small), the light variation is far less than it is for a star.

Sir / I just wanted to drop a line to say how very much I appreciated your November issue.

Knowing that I should be spending Christmas in the Fiji Islands which, for me, would be the first time south of the equator, I set it aside and took it with me. "The Southern Sky" by Henry J. Phillips could not have been more useful.

In spite of the wet season, we had several good nights for observing. I must confess that without this article I would have been completely lost. It was as if I had been transported to another part of the galaxy! Initially I couldn't pick out anything. Clouds over the northern part of the sky finally cleared away and I was able to pick up Orion — seen with northern hemisphere chauvinism — upside down! From there I worked south step by step, night after night, using Canopus, Achernar and Alpha Pavonis as my anchor points. By sitting up most of the night I was able to cover the sky from Pavo through Vela, Carina and Centaurus, as far as Lupus and Norma — a fair sweep of the sky, I thought.

While I agree with most of the points made in the article, I feel we have a rich-

er sky in the north! The area from Vela to Centaurus is magnificent by any standards. South of that, in Apus, Octans and Mensa, I had difficulty seeing anything at all. Incidentally, a small point: Mensa is the Latin for "table" — not "mountain", as stated in the article.

Thank you again. I certainly would recommend that any ASTRONOMY reader take this issue along when traveling south.

GRAHAM L. ANDERSON
Cowichan Bay, British Columbia
CANADA

Sir / I would like to make a suggestion concerning your ads with order blanks that must be cut out. I've been receiving ASTRONOMY for two years and have saved every issue. Personally, I'd rather not cut anything out, especially since many order blanks contain part of an article or picture on the reverse side.

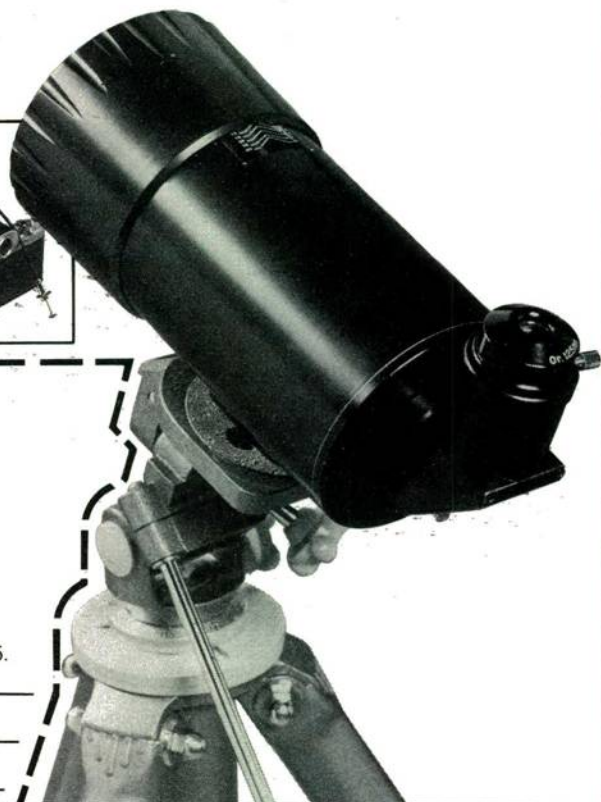
CRAIG CARSON
Bay City, Mich.

Mr. Carson / It isn't necessary to cut out the coupons in ASTRONOMY or any other magazine. Simply write the necessary information neatly on a clean sheet of paper or make a photocopy of the coupon and send it in. Our advertisers appreciate that readers do not wish to damage their copy of the magazine. Do be sure you include all the information, and be sure to tell them you saw their ad in ASTRONOMY.

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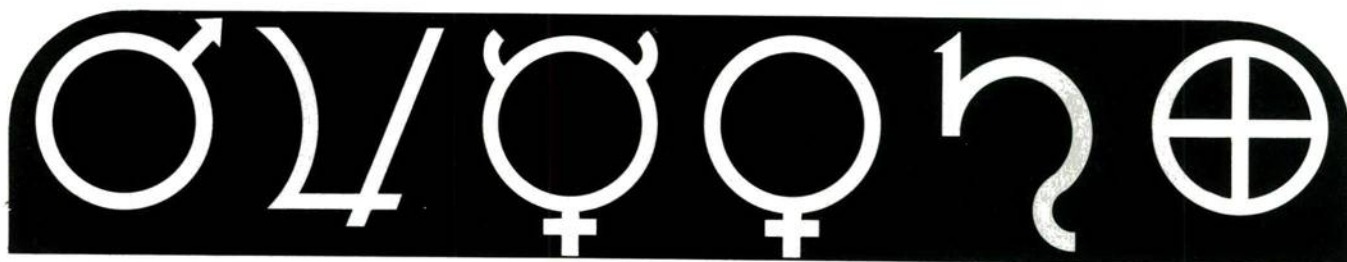
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SKY ALMANAC

Conjunctions, Asteroids and the Sun!

by
Robert Burnham

Summer months are the peak ones for observing: Nights are warm and skies bright, and the short nights make all-night observing sessions feasible. Unfortunately this is a relatively poor month for planet watchers. While there is an impressive conjunction or two, the attraction lies more in the configurations of the planets rather than the detail on their disks. Four of the five planets visible to the naked eye will set soon after the sun, leaving the sky to the moon and stars.

On the other hand, the four brightest minor planets (Ceres, Juno, Vesta and Pallas) are well placed for observing. Two of them come to opposition this

month, and one may *just* be visible to the naked eye. Another good object to look at now is the sun — often neglected by observers who tend to concentrate their efforts on the night sky.

Sun

Every 11 years the number of spots on the face of the sun undergoes a cyclic change. The cycle begins with the maximum number of spots, reaches minimum in approximately 5-1/2 years and swings back to maximum at the end of the 11 years. This year marks about the midpoint in the rise to maximum for this cycle. Since March 1976, sunspots have been increasingly more frequent. If you go out and observe now, you're

almost assured of seeing some. It's not hard to observe sunspots, but you *must* take safety precautions or you'll blind yourself painfully and permanently.

The safest way — as well as the way best suited to sketching — is the projection method. You start by aiming the scope at the sun — but *do not look through it!* Look instead at the ground below the scope. Swing the tube around until the shadow of the tube is as small as possible. When you've done this, the tube is properly aimed. It's a good idea to cover the aperture of the finderscope (if you have one), since you can get a nasty burn by putting your hand or arm accidentally behind the finder's eyepiece.

With the telescope aimed, hold up a sheet of paper or cardboard about 10 to 12 inches behind the eyepiece. You'll find the image of the sun projected on it. You can sharpen the image by focusing as you normally would. (If you're using a refractor, it might be worth the trouble to mount a cardboard screen up the tube by the objective, so that the

July Positions for Mercury, Venus, Saturn, Regulus

Object	Date	Right Ascension	Declination	Magnitude
Mercury	July 15	9 ^h 22 ^m 06 ^s	15° 47' 39"	+ 0.4
	July 26	10 ^h 02 ^m 35 ^s	10° 10' 06"	+ 0.8
	July 31	10 ^h 11 ^m 55 ^s	8° 10' 13"	+ 1.1
Venus	July 10	10 ^h 01 ^m 24 ^s	13° 46' 32"	- 3.6
	July 15	10 ^h 22 ^m 58 ^s	11° 34' 15"	- 3.6
Saturn	July 10	10 ^h 03 ^m 17 ^s	13° 28' 16"	+ 0.9
	July 15	10 ^h 05 ^m 22 ^s	13° 16' 51"	+ 0.9
	July 19	10 ^h 07 ^m 06 ^s	13° 07' 25"	+ 0.9
	July 21	10 ^h 07 ^m 58 ^s	13° 02' 36"	+ 0.9
	July 26	10 ^h 10 ^m 12 ^s	12° 50' 20"	+ 0.9
	July 31	10 ^h 12 ^m 29 ^s	12° 37' 45"	+ 0.9
Regulus	July (all month)	10 ^h 07 ^m 12 ^s	12° 04' 31"	+ 1.3

July is a prime month for observing the North America and Pelican nebulae, as pictured here. The nebulae are situated a few degrees to the north and west of Deneb in the constellation Cygnus. This shot was taken with an eight inch f/1.5 Schmidt, for a 35 minute exposure on Fujichrome 100 film. Photograph by Andrew Toth and Joseph Glowacki.





image isn't washed out by the direct rays of the sun. Newtonians and Cassegrains won't need this.) The projection method is beautifully simple and safe. What's more, it lets many bystanders see the sun at one time. You could set up shop as the "solar expert" on your block and give astronomy lessons!

As you observe for several days, you'll see the spots come around the eastern limb and move out onto the face of the sun. While they are close to the limb, sunspots often look like indentations in the sun's surface. If you're lucky and continue observing, you might see a spot or group of spots come around a second time. Since the sun rotates once in about 27 days, this would be a very long-lived feature. Sketches will help you identify any such group.

Sketching sunspots is really simple. You'll need a sheet of paper (8-1/2x11 inches is fine), a clipboard or other stiff support, a compass and straight edge, and a medium soft pencil (HB grade is ideal). Draw a circle about six inches in diameter on the paper with the compass (or trace around a can or glass). Draw a straight line across the top of the circle just touching it. Make a tick mark in the line where it touches the circle. Attach the paper to the clipboard, using tape if necessary to hold it firmly.

Hold the clipboard up to the projected image and put it far enough away so that the sun just fills the circle. Then turn off the clock drive (if your scope has one) to allow the sun's image to drift across the paper. Rotate the clipboard so that the drift goes along the line. You have now established the east-west direction, with west being the side the image drifted toward. *Keeping the paper oriented*, take your pencil and copy the sunspots onto the paper! You'll be surprised how easy it goes with a little practice. When you've finished, be sure to record the date, time and orientation of the

Top left: Although the upswing to the maximum of the sunspot cycle was supposed to begin two years ago, no significant activity was detected until early this year. This sunspot group was photographed on Feb. 12 using the eyepiece projection method with a Solar Skreen filter on an eight inch Celestron. Kodachrome film (ASA 64) was used for the 1/15 second exposure. **Top right:** This shot of the solar disk was taken with an eight inch Celestron at prime focus using a #12 Solar Skreen filter on Kodachrome film (ASA 64), exposed for 1/90 second. Photographs by James Felbab. **Bottom:** On July 10, Venus and Saturn will be separated by 0.1 degree. The scene should look very similar to this one (the separations are the same) which was taken on July 30, 1974. If you look closely just to the left of center, you should see Mercury, one of our solar system's more elusive planets. This shot is a 20 second exposure on High Speed Ektachrome (ASA 160), taken with a 10 inch f/8 Newtonian reflector. Photograph by Larry Koehn.

Positions and Magnitudes of the Minor Planets

Asteroid	Date	Right Ascension	Declination
Pallas	July 1	16 ^h 51 ^m 11 ^s	+24°59'12"
	July 15	16 ^h 43 ^m 46 ^s	+23°16'28"
	July 31	16 ^h 40 ^m 10 ^s	+20°38'49"
Visual Magnitude on July 21 — +9.1			
Vesta	July 1	16 ^h 29 ^m 19 ^s	-17°05'51"
	July 15	16 ^h 24 ^m 00 ^s	-18°07'53"
	July 31	16 ^h 25 ^m 59 ^s	-19°29'22"
Visual Magnitude on July 21 — +5.9			
Ceres	July 1	19 ^h 23 ^m 39 ^s	-28°58'41"
	July 15	19 ^h 10 ^m 14 ^s	-30°04'03"
	July 31	18 ^h 56 ^m 09 ^s	-30°53'51"
Visual Magnitude on July 21 — +7.1			
Juno	July 1	20 ^h 18 ^m 33 ^s	-3°40'50"
	July 15	20 ^h 08 ^m 10 ^s	-4°13'56"
	July 31	19 ^h 54 ^m 18 ^s	-5°30'52"
Visual Magnitude on July 21 — +9.2			

image. (Don't forget ASTRONOMY would be delighted to see your sketches.)

Mercury, Venus, Saturn

We'll discuss these three planets together this month since they will all occupy much the same part of the sky for most of July. The planets will perform a complicated ballet in western Leo throughout the month, moving around in the vicinity of the star Regulus. The big catch is that the area lies near the sun and will be close to the western horizon at sunset. Moreover, a strong ruddy twilight glow will greatly reduce the contrast between planet and sky, making the planets harder to see.

Mercury, true to its name, dashes from the western side of Cancer across that constellation, moving into Leo on the 14th. While the innermost planet closes in on Regulus, Venus, a few degrees north, is doing the same (though more slowly). Meanwhile Saturn, only a couple degrees northwest of Regulus, is traveling in direct motion (west to east) on a path that takes it a degree due north of the star on the 19th, and closest to Regulus on the evening of the 21st. Venus overtakes Saturn on the 10th, grazing by just 0.1 degree north of the ringed planet. This will be a very pretty sight in a telescope! The ball of Saturn will be about 15 seconds of arc in diameter. Venus will look like a small first quarter moon and will be the same size as Saturn. This coincidence happens because Saturn, physically 10 times larger than Venus, will be 10 times farther away!

Mercury will meanwhile be drawing rapidly east of the sun, reaching its greatest elongation (27 degrees) on the 22nd. That sounds like a good distance, but because of the angle its orbit makes with the path of the ecliptic, it won't get any higher above the horizon than about 15 degrees at sunset. At magni-

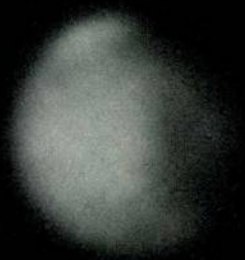
tude 0.6, it looks like a tiny first quarter moon only 7.8 seconds of arc in diameter through a telescope. (Both Mercury and Venus show phases, and Galileo's discovery of this helped him believe in the Copernican system.) On the 26th, Mercury will be passing about four degrees southwest (closest approach) of Saturn, reaching conjunction five days later — on the 31st — when it's five degrees south of the planet.

These conjunctions are very photogenic. Nearly any camera will show something, provided it can be set to take a time exposure. The normal lens supplied on cameras will "take in" a piece of sky about 30 degrees square or more, depending on film format. This is ample for scenic shots with the planets above a dark evening horizon. A telephoto lens will move in on the action, so to speak, and with a telescope, planetary shape can be shown. Exposures are really a matter for trial and error. It's always good to bracket your exposures (go at least two stops over and under your best guess), even when your meter tells you what it should be. Remember, film is cheap when the event is nonrecurring! ASTRONOMY is interested, of course, in seeing any good photographs of this conjunction.

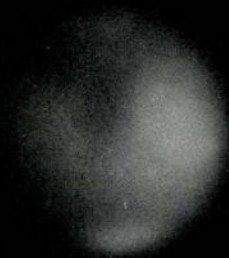
Moon

In the early morning of the 2nd, the moon (three days before new) will slide along the south part of the Hyades star cluster in Taurus and will appear as a slim crescent only seven percent lit. You'll see a conjunction of the moon and +0.9 magnitude Aldebaran from most of the United States and Canada. However, if you live north of a line from San Francisco through the Great Salt Lake, and Lake of the Woods to James Bay, you'll see the moon occult the star! You'll have to look carefully since the disappearance is on the bright limb of the moon and the reappearance is after sunrise.

MARS



Dec. 28, 1977 10:20 p.m.



Dec. 28, 1977 11:05 p.m.



Dec. 29, 1977 12:03 a.m.

JUPITER



Dec. 28, 1977 9:05 p.m.

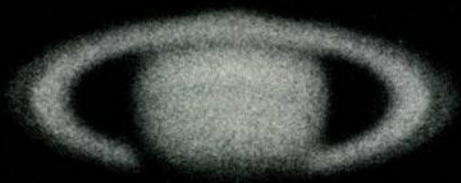


Dec. 28, 1977 9:20 p.m.



Dec. 28, 1977 9:55 p.m.

SATURN



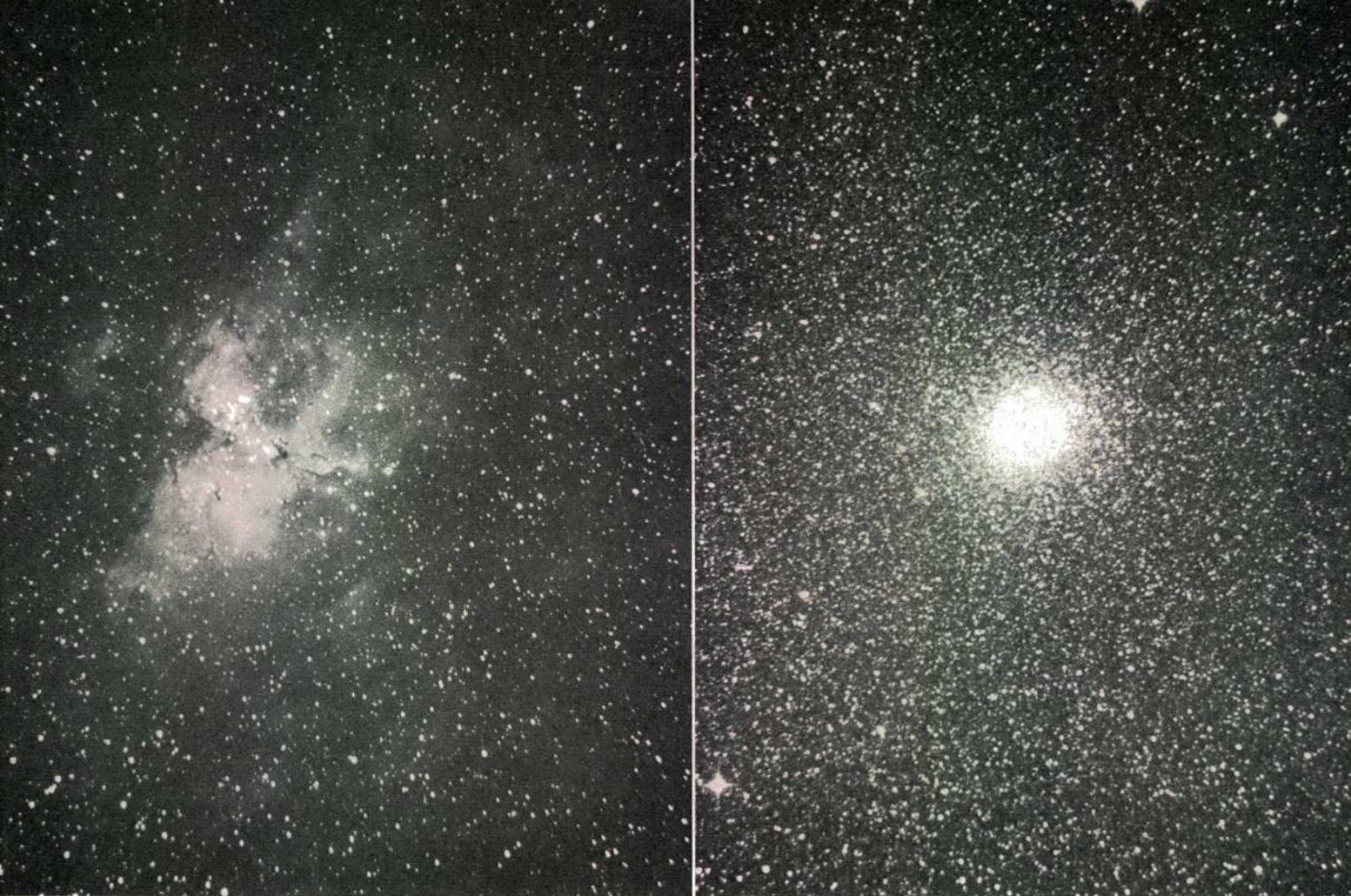
Feb. 14, 1976



Feb. 11, 1977



Feb. 28, 1978



Opposite page, top row: This series of photos taken in December 1977 (24 days prior to opposition) show the rotation of Mars' north polar cap and one of its dominant features, Syrtis Major. The photographs, exposed for four seconds each on Panatomic X film, were taken with an eight inch f/5 reflector. Photographs by Lester Yuill. Center row: The rotation of Jupiter's Great Red Spot is shown in this series of photos taken six days after opposition. An eight inch f/5 reflector was used for the eight second exposures on H&W Control film. Photographs by Lester Yuill. Bottom row: In its 29.5 year orbit around the sun, Saturn's rings take on a varied appearance. In 1973, the rings were inclined to their fullest extent (27 degrees), and by 1980 will be positioned edge-on — making it

Mars

As the month begins, Mars is setting about three hours after the sun. Moving from Leo into Virgo, it will cross the boundary on the 25th. At that time it will be just over two astronomical units (186,000,000 miles, or 300,000,000km) distant from Earth. You'll find it about 12 degrees south of Denebola, the +2.1 magnitude star at the tail of the lion. Mars itself isn't much brighter — only +1.7 — and it may be easy to overlook it in the evening glow. It's a disappointing sight in a telescope, at only about five seconds of arc diameter.

almost impossible to see them. This series of photos of the southern edge of the rings and the southern hemisphere show how the tilt changes within a three year period. Each photo was exposed for three seconds on Tri-X using an eight inch Newtonian reflector. Photographs by Bob Kimmel. Above: These two photographs, M-16 (the Eagle nebula) on the left and M-22 (globular cluster) are prime targets for photographing in July. The Eagle is situated to the north of Sagittarius and west of Scutum. The globular cluster is located to the east of the "teapot's dome" (a synonym for Sagittarius) and north of Nunki. Both photos were taken with a 10 inch f/5 Cave Newtonian reflector at prime focus using 103aE film; M-16 and M-22 were exposed for 20 and 15 minutes respectively. Photographs by Lee Coombs.

Jupiter

On the 10th Jupiter will be six minutes of arc north of the sun, moving through superior conjunction. The sun's glare will wipe out your chance of seeing the giant planet until late in the month when it can be seen in the morning sky at about magnitude -1.4, rising 1-1/2 hours before the sun.

Uranus

Uranus is a pale disk of +5.8 magnitude, almost stationary in western Libra. You'll find it about one degree west of Zubenelgenubi. If you aren't sure

which star this is, look for Alpha Librae! Since Uranus is more than 1,700,000,000 miles (2,700,000,000km) distant, it shows a disk of only 3-1/2 seconds diameter. It passes opposition in early May and is now growing smaller and dimmer all the time. It transits about 8 p.m. local daylight time in the middle of the month.

Neptune

Neptune can be found in northern Scorpio, amidst the stellar clutter of the Milky Way's edge. On the 15th its position is 17 hours 00 minutes right ascension, and -21 degrees 14 minutes declination (1950 coordinates). It is faint (magnitude +7.7), and with a diameter of 2.5 seconds of arc, you'll have a hard time distinguishing it from a star unless your telescope is moderately large (at least eight inches). Even if you have a small scope, you can still find it by locating the field and sketching the positions of all the stars you see. If you look again the next night, you'll know Neptune because it is the one "star" that moved!

Asteroids

Locating and tracking asteroids is a very good way to sharpen your observing skills. By starting with the four brightest and gradually learning the techniques, you'll be equipped to go after the fainter ones.

Two of the four bright asteroids come to opposition this month: Ceres on the 9th, and Juno on the 24th. The other two are now receding in distance and brightness. The May 1978 Gazer's Gazette ("The 'Big Four' Asteroids") has excellent finder charts for all four asteroids, but if your copy is not at hand, use the positions and magnitudes printed in the box on page 23.

On July 1, Ceres will be 2-1/2 degrees west-northwest of M-55, a large and bright globular cluster. Ceres will be magnitude +7.0, and like all asteroids, will be indistinguishable from a star (hence the name "asteroid"). The way to tell them apart is to plot the field where the asteroid is and check it again the next night. The one "star" that moved is the asteroid. (This was the way all asteroids were discovered before the use of photography.) Make a quick sketch, or take a picture through your telescope if you have the equipment. The photographic way is obviously more accurate, but a pencil sketch works fine for finding an asteroid.

On the 26th, Ceres will pass about one degree southeast of the +2.6 magnitude star, Zeta Sagittarii. If you have a low power eyepiece, try to get both into the same field of view. The two will show an interesting color contrast: Zeta is a hot star — much hotter than the sun — and so gives off a bluish light. Ceres is lit by our sun and looks yellowish!

Juno will be a bit harder to see than Ceres. It is over two magnitudes fainter (+9.3) and is also in a relatively rich Milky Way area in southwest Aquila. On the 9th it will pass by a double star, missing it by about 1/2 degree. The double, designated Struve 2654, is 3-1/2 degrees southwest of Theta Aquilae, and has component stars of +6 and +7.5 magnitudes. A medium to low power eyepiece will show the double and the asteroid, but use as low a power as necessary.

On the night of the 20th, Juno will be a few minutes of arc south of SAO 144070, a +7.0 magnitude star. This grouping should give a slight color contrast. The star is type A0, a white star, and with Juno being yellowish, you should see a contrast. Four days later Juno passes SAO 144009, +6.7 magnitude and also an A0 type, making another contrast comparison.

During the beginning and end of the month, Vesta moves through Ophiuchus — but for an 11 day period in the latter half of July, it will cut across a corner of Libra. Vesta is the brightest (+5.8 magnitude) of these four asteroids, both in appearance and reflectivity. Almost half (45 percent) the light falling on it bounces off. The others aren't nearly as reflective: Juno, 27 percent; Ceres, 13 percent; Pallas, 11 percent. Because of its brightness, sometimes you can just see it with the naked eye, though it takes a dark sky and patience.

On the 16th Vesta swings a few minutes west of Chi Ophiuchi. At 8 p.m. EDT on the 16th, Vesta will be only five minutes to the northwest of Chi. Shining bluish white, Chi is a spectral type B2 star of +4.3 magnitude. If you can, try to get a series of pictures showing the conjunction of Vesta and Chi.

Pallas, the last and dimmest of the four, is in Hercules the whole summer. Since it is at magnitude +9.0, you won't have an easy time finding and tracking it! On the 3rd it will slip by to the south of 51 Herculis, missing it by a couple minutes of arc. Pallas will be four whole magnitudes fainter than this star! On the 14th it will be 3/4 degree east of the double star Struve 2094. On the 25th it grazes another double, Struve 2085, passing it 1/4 degree to the east.

One of the major tests of an astro-photographer is to record an asteroid in a photograph and *show its motion*. You'll need a dark sky, accurate predictions of its position, a long focal length telescope with camera, and plenty of patience. Run a long exposure (at least an hour) centered on the position of the asteroid, and then check the film when developed for a trail. If you've done the guiding properly, the stars should be points and the asteroid will be a short streak. This is difficult, but the reward is all the greater — especially since relatively few astronomy enthusiasts try it. ☛

Upcoming Events for August

- | | |
|---|--|
| 3 New Moon | 12 Perseid meteor shower—50 per hour |
| 5 Moon passes 4 degrees south of Saturn | 14 Venus 1.2 degrees south of Mars |
| 7 Jupiter 7 degrees south of Pollux | 18 Full Moon |
| 8 Moon passes 0.4 degrees north of Venus, visible as an occultation from East Asia, North Pacific and Central America | Mercury at inferior conjunction |
| | 25 Last Quarter Moon |
| | 27 Saturn in conjunction with sun |
| 11 First Quarter Moon | 29 Venus at greatest eastern elongation—46 degrees |

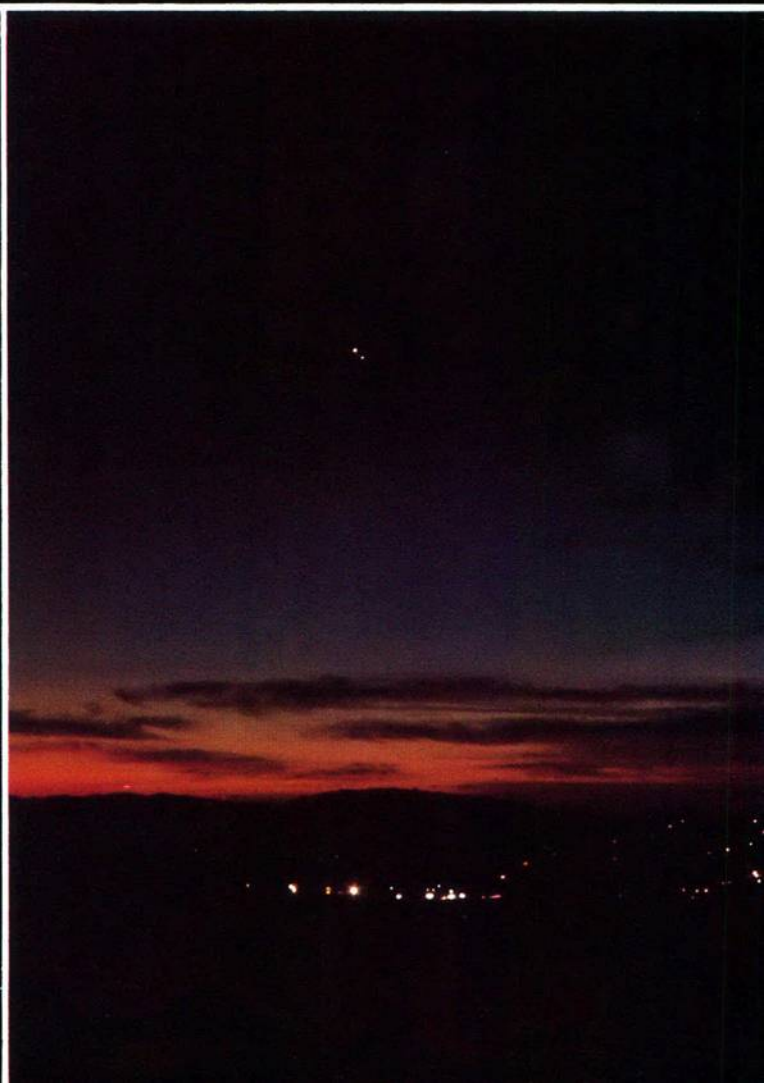
Mercury is poorly placed for observing in August. Early in September, the planet will be at greatest western elongation, and will then be fairly easy to spot. At magnitude -3.8, Venus dominates the western horizon and sets about 1-1/2 hours after sunset. The planet reaches greatest eastern elongation (46 degrees) on the 29th and will be visible 18 degrees above the horizon at sunset. Mars is located in the constellation Virgo and can be seen low above the southwestern horizon at sunset, setting about 1-1/2 hours later. Jupiter, at magnitude -1.4, enters the morning sky and is in the constellation Gemini, rising about two hours before sunrise. This month Saturn is in conjunction on the 27th and is too close to the sun to be seen.

Perseid Meteor Shower

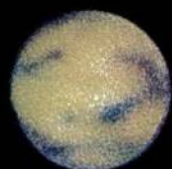
This year we'll see one of the better Perseid meteor shows. (In past years the moon has interfered by flooding the sky with light.) You should be able to see about 50 meteors per hour, all apparently coming from a spot in the constellation Perseus, near the Double Cluster between Perseus and Cassiopeia. The predicted date of maximum is Aug. 12, and the peak is fairly sharp,

since five days either side of the 12th will show only 1/4 as many meteors as the maximum. As with all meteors, the best time to observe is in the wee hours of morning — when you are on the "leading" hemisphere of Earth as it sweeps along in its orbit. Just as the front end of a car picks up more bugs than the back end, so does the meteor rate increase for observers on the morning half of the night side of Earth.

Opposite: In the March 1978 issue of *ASTRONOMY*, we omitted any information about the lunar eclipse of March 23-24. Although the eclipse wasn't visible for most of North America, observers in Australia and Hawaii were able to send in the photos you see on this page. Top: From Australia, this shot shows the moon moments before totality. It was taken with a four inch reflector and teleadapter using the eyepiece (40mm) projection method. The exposure was 30 seconds on High Speed Ektachrome (ASA 200). Photograph by Eddie Gainsford. Bottom left: According to the photographer, this slide "isn't really half as rotten as it deserves to be!" It seems Coryell got started up the hill to his chosen observing site too late, had the wrong lens on his camera, his flashlight kept going out, one of his dogs knocked over the tripod, he couldn't find his ASA 200 Ektachrome so he had to use ASA 64, and at one point the trunk lid fell on his head! *ASTRONOMY* applauds his superhuman effort. The partially eclipsed moon is shown hanging over the suburbs of Honolulu in this shot taken with a Nikkormat camera which had a 105mm lens at f/3.5 for the five second exposure. Photograph by Roger Coryell. Bottom right: Aside from their astronomical significance, conjunctions often provide a very attractive sight. This evening shot of Jupiter and Venus, separated by 0.2 degree, was taken in February 1975 — yet it has a timeless quality about it. Fujichrome 100 film was used for the one second exposure. Photograph by Pat Michaud.



Planet Finder

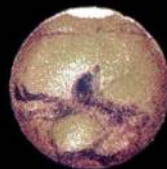


(A) Mercury

July 1
R.A. 7h56m
Dec. +22°38'
Mag. -0.4

(B) Mercury

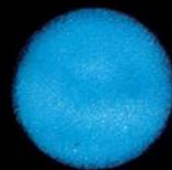
July 15
R.A. 9h22m
Dec. +15°47'
Mag. +0.4



(M) Mars

July 1 15
R.A. 10h45m 11h15m
Dec. +8°55' +5°35'
Mag. +1.6 +1.7

(C) Ceres
July 1 15
R.A. 19h23m 19h10m
Dec. -28°58' -30°04'
Mag. +7.1 +7.1



(N) Neptune

July 15
R.A. 16h59m
Dec. -21°14'
Mag. +7.7



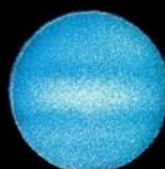
SUN

The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.



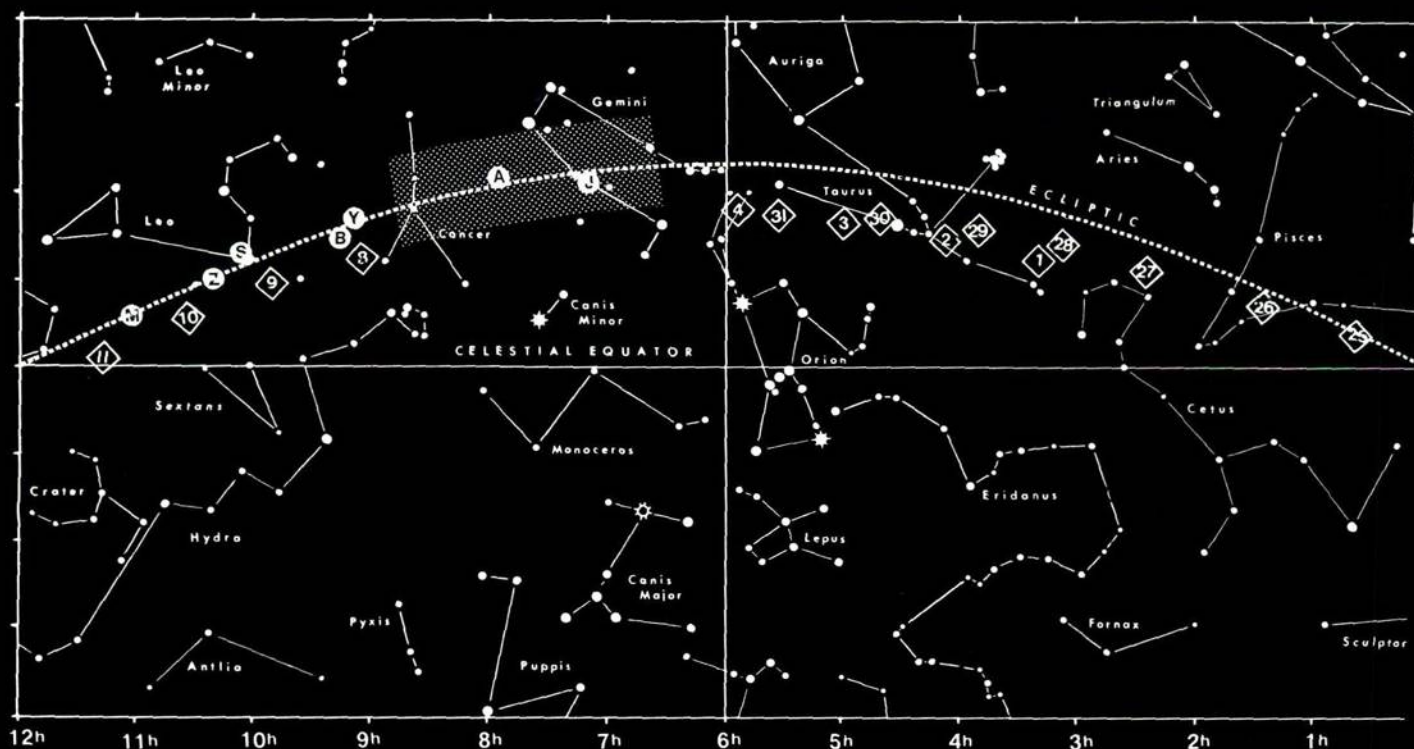
(S) Saturn

July 1 15
R.A. 9h59m 10h05m
Dec. +13°47' +13°16'
Mag. +0.9 +0.9



(U) Uranus

July 15
R.A. 14h40m
Dec. -15°10'
Mag. +5.7



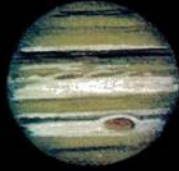
The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec. = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag. = magnitude, a

July 1978



(V) Vesta

July	1	15
R.A.	16h29m	16h24m
Dec.	-17°05'	-18°07'
Mag.	+5.7	+5.8



(J) Jupiter

July	1	15
R.A.	7h08m	7h21m
Dec.	+22°38'	+22°15'
Mag.	-1.4	-1.4



(Y) Venus

July	1	
R.A.	9h21m	
Dec.	+17°23'	
Mag.	-3.5	

(Z) Venus

July	15	
R.A.	10h22m	
Dec.	+11°34'	
Mag.	-3.6	

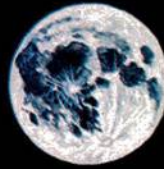


(P) Pluto

July	15
R.A.	13h16m
Dec.	+10°19'
Mag.	+14



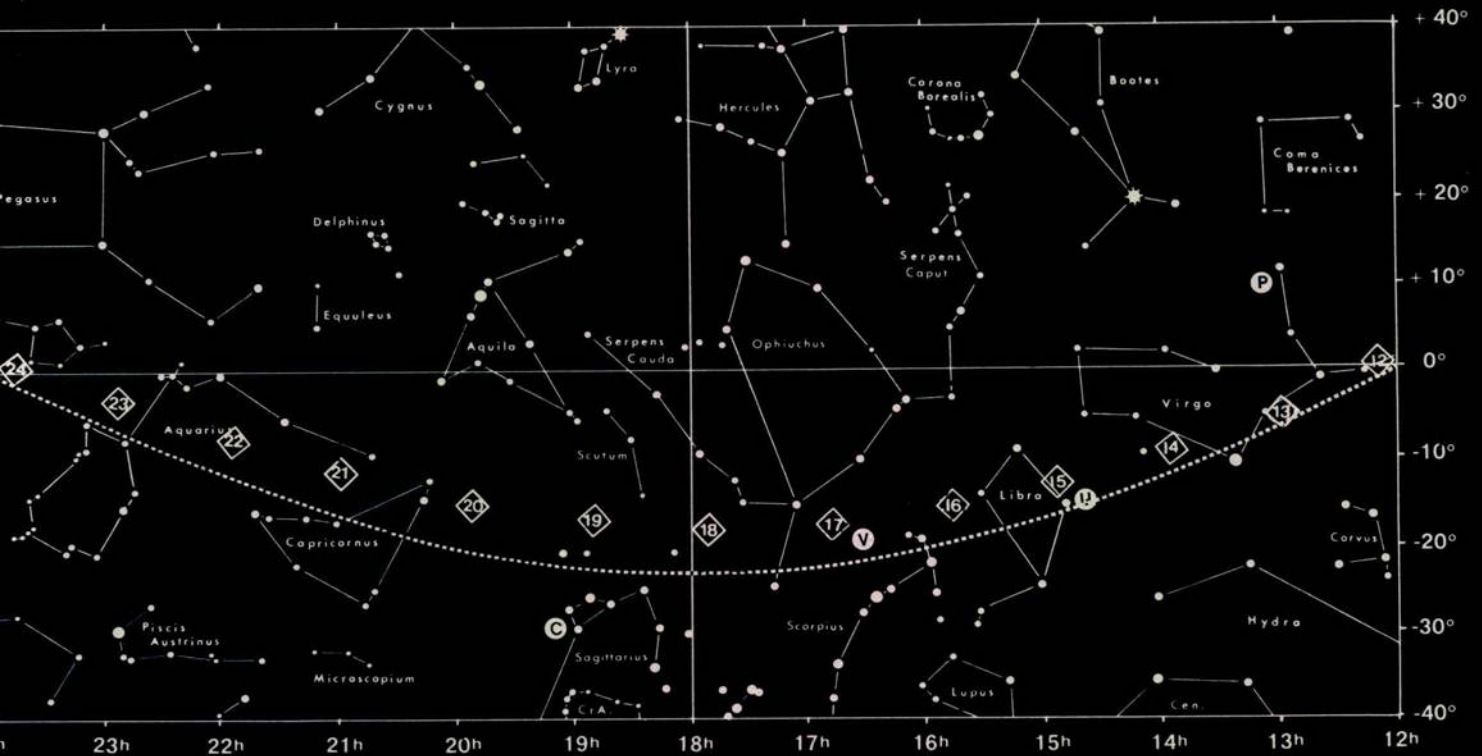
First Quarter
July 13



Full Moon
July 19



Last Quarter
July 26



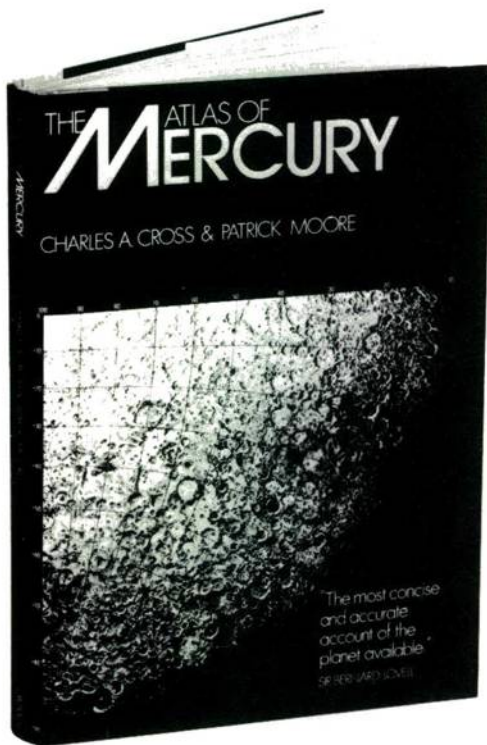
measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month; the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.

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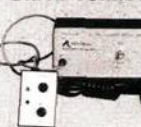
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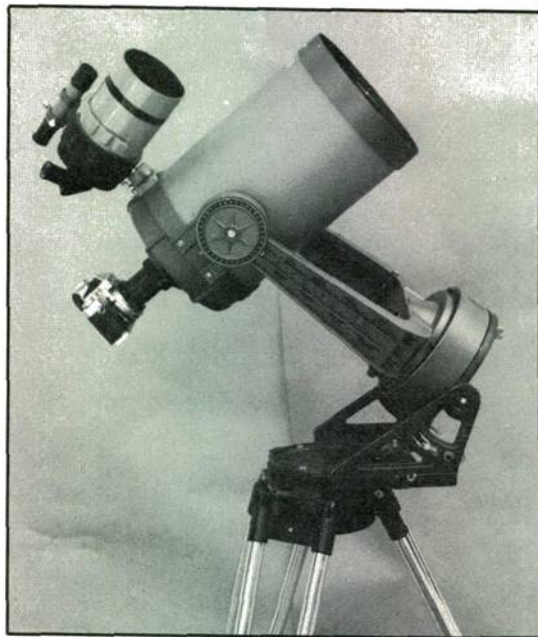
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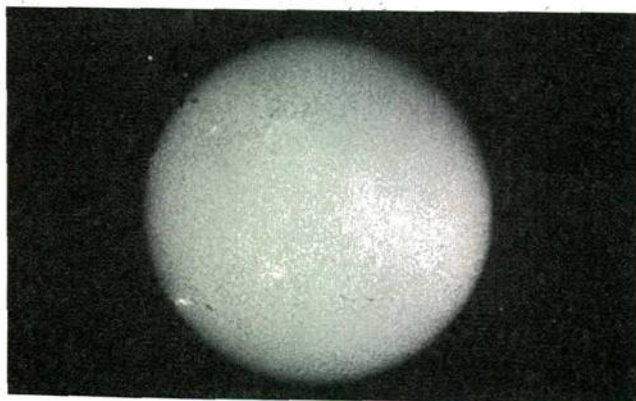
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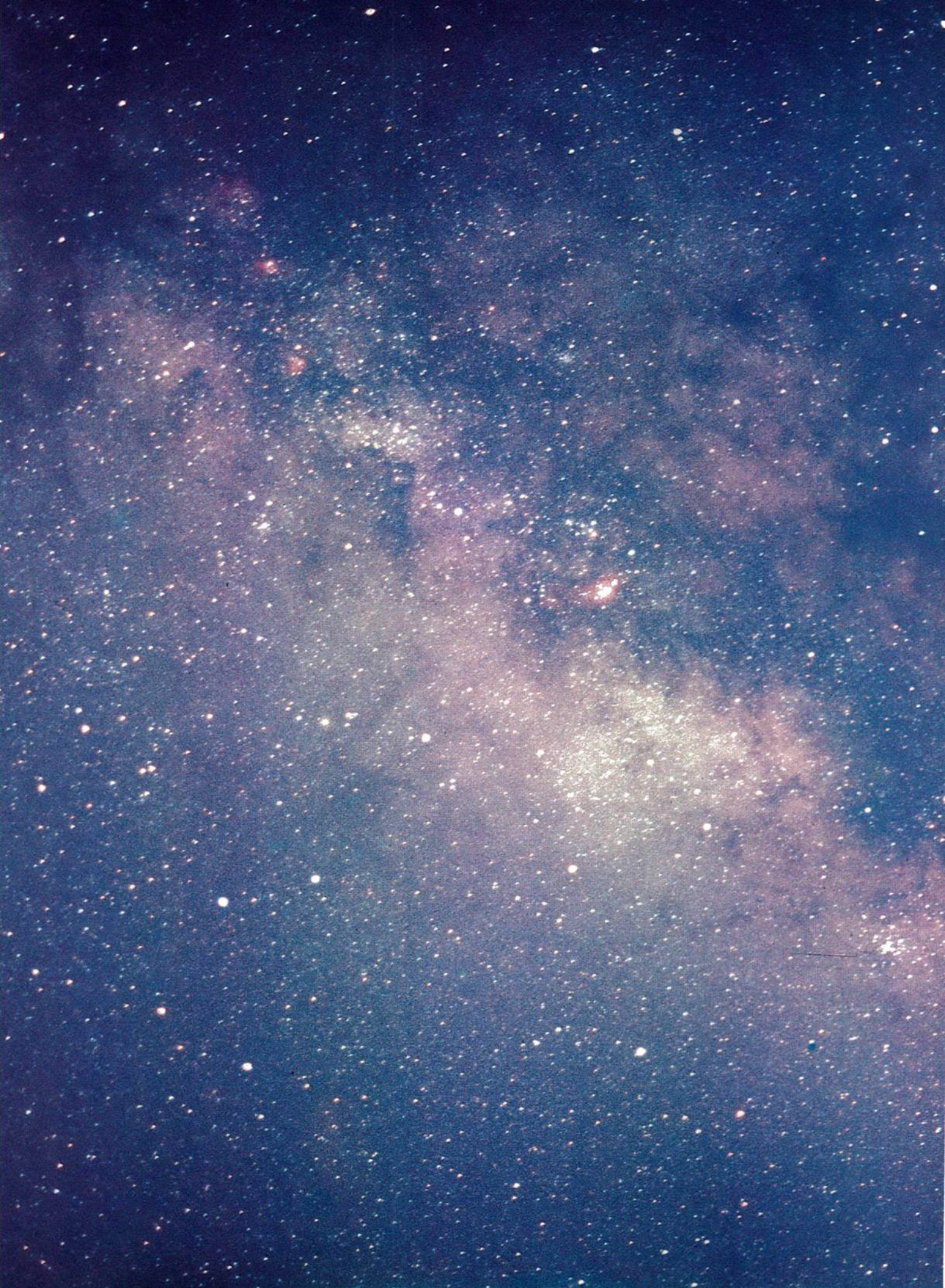
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Learning the Constellations – Part 3: Summer

by
Henry J. Phillips

More people look at the stars during the summer than at any other time of the year — certainly an understandable state of affairs, given the prevailing warm weather conditions. You're just more likely to want to go outside on a summer evening than you are during cooler seasons, and you'll probably have more leisure time on your hands. Whether you've read the first two articles in this series (ASTRONOMY, December 1977 and April 1978), or you're just starting out now, it's a fine time to go out and look at the stars!

Bootes, the last of the spring constellations, is readily visible most of the summer, and orange Arcturus, its brightest star, serves as an excellent starting point for the study of summer's star groups. Just east of Bootes lies a fairly small circlet of stars known as **Corona Borealis** (ko-ROH-nah bo-ree-AL-is), the northern crown. The constellation does resemble a glittering diamond tiara; the brightest star of the group has two alternate names, *Alphecca* (al-PHEK-ah) or *Gemma* (JEM-ah). Choose the name you prefer; both titles have their adherents. Corona Borealis is easy to find and recognize, and it's an attractive group.

On the other side of Corona Borealis from Bootes lies a collection of four stars that forms a lopsided square. These stars are known as the *Keystone*, the most prominent part of the constellation **Hercules** (HER-kyoo-leez), named after a famous hero in Greek mythology. Hercules is a very large constellation, but most of its stars are faint, and you may have a little trouble tracing out its pattern unless the sky is completely clear and moonless. The Keystone is at the

western edge of the constellation; the rest of it sprawls away from the Keystone in three directions.

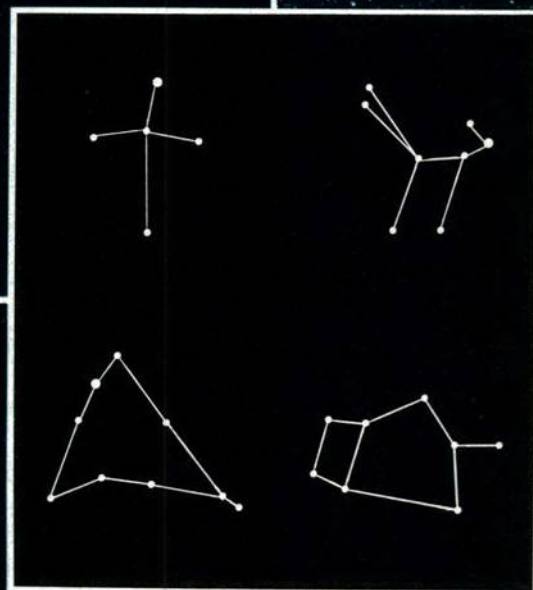
North of Hercules is a constellation that never sets for most observers in the northern hemisphere, due to its proximity to the sky's north pole. This is **Draco** (DRAY-koh), the dragon. Draco twists around the Little Dipper before doubling back and ending just north of Hercules; its most readily seen feature is the head, made up of four stars located above Hercules' northern border. The brightest star in the head is *Eltanin* (el-TAN-in). Face north to find Draco; it's most easily seen during the summer, when the stars in the head pass almost directly through the zenith.

Returning to Corona Borealis, we find an X-shaped group of stars just south of it. The X marks the head of **Serpens** (SIR-pens), the serpent. A line of stars directly south of the X traces out the rest of the constellation — or, we should say, of this *part* of the constellation. Serpens is the only constellation in our sky which is broken into two parts: the head, known as **Serpens Caput** (KAH-put), and the tail, called **Serpens Cauda** (KOW-dah). Separating the two sections of the snake is the giant constellation **Ophiuchus** (oh-fee-YOO-kus), the serpent holder.

In ancient times Ophiuchus was figured as a man holding the serpent in his hands. You will search in vain for any resemblance to this man in Ophiuchus' stars; what you *will see* is a large, roughly pentagonal figure, marked at the top by the second magnitude star *Rasalhague* (RAS-sle-haig). Other fairly bright stars outline the rest of the pentagon; the whole isn't difficult to make out on clear nights.

South of Ophiuchus is a much brighter star group: the magnificent constellation **Scorpius**, (SKOR-pee-us), the scorpion. Scorpius really does resemble the object it's supposed to be; you can see the claws at the western edge of the group, with the scorpion's body twisting south and east, and the whole

For observers in the northern hemisphere, the summer months provide the best view of the Milky Way — whether it be for photographing or just plain enjoyment. The Sagittarius star-cloud region in the southern portion of the Milky Way is vividly captured in this 17 minute exposure taken with a 35mm camera using a 55mm lens at f/1.8 on GAF 500 film. Photograph by Don Doerfler.



ending in the animal's upraised sting. Scorpius contains many bright stars, and the leader of the group is the red first magnitude star *Antares* (an-TAH-reez). This greek name means "rival of Mars"; when the planet Mars is moving through Scorpius (as it will, since Scorpius lies in the zodiac), you can easily see that the two have the same red color. Scorpius is such a grand constellation that it's a shame it lies so far south, scraping the horizon for observers in northern or middle latitudes. The farther south you live, the better view you'll have of this group

Ophiuchus is also in the zodiac, although it's not counted among the "official" 12 constellations in that band (probably for superstitious reasons, for the addition of Ophiuchus would make their number 13). You can expect to see the moon or a planet in the southern reaches of Ophiuchus at one time or another. You can also see them in *Libra* (LEE-brah), a dim group to Scorpius' west. *Libra* doesn't contain bright stars or a readily recognizable pattern; it does contain one star (its brightest) that is said by many to be green in color — the only green naked eye star. What color does it look like to you?

Yet another zodiacal constellation is found east of Scorpius. This group is called *Sagittarius* (saj-it-AIR-ee-us), the archer. Sagittarius has no first magnitude members, but its main stars are quite bright and you should have no trouble locating them. They are arranged in a pattern that strikingly resembles a teapot, which is tipped in such a direction that we can imagine hot tea being poured onto the nearby scorpion's sting! Like its neighbor, Sagittarius lies fairly far south, so horizon haze or low lying clouds may occasionally trouble you. Just beneath the teapot is *Corona Australis* (ko-ROH-nah aus-TRAH-lis), the northern crown's southern counterpart. Corona Australis does resemble Corona Borealis quite closely, except that Corona Australis lacks a bright star like Alphecca/Gemma.

Moving farther north again, we find east of Hercules a very large triangle of first magnitude stars. These three luminaries make up the summer triangle, one of the most distinctive features of the summer sky. The triangle is not a constellation in itself, but the three bright stars that comprise it are the brightest members of their respective groups. They are *Vega* (VAY-gah) in the constellation *Lyra* (LIE-rah); *Deneb* (DEN-ebb) in *Cygnus* (SIG-nus), and *Altair* (AL-tare) in *Aquila* (ah-KWIL-ah).

Of these three stars, the brightest is Vega. Vega is, in fact, the brightest of all the summer stars. It is bluish in color and passes almost overhead on August evenings. Lyra the lyre, in which it lies, contains no other stars that remotely resemble Vega in brightness, but the group's pattern is easy to recognize: a small triangle (including Vega) attached to a parallelogram. Lyra is rather small, but easy to find nonetheless (the presence of Vega certainly helps!).

Cygnus the swan lies east of Lyra, and its stars form a cross (the group is often referred to as the *Northern Cross*, much larger than its more famous southern namesake). Deneb is at the top of the cross, and is the brightest of the stars in it, shining with a clear white light. At the foot of the cross is the star *Albireo* (al-BEER-ee-oh), well known because it's one of the most beautiful double stars in the sky; its components are orange and blue. If you or a friend own a small telescope, don't pass up the chance to look at Albireo through it.

South of these two constellations is *Aquila* the eagle. Its most distinctive feature is a row of three stars that bears a striking resemblance to Orion's belt. The middle of the three stars is Altair, outshining its two companions. Altair is midway between Vega and Deneb in brightness, and is also white in color. The rest of *Aquila* lies south of this threesome.

Between Cygnus and *Aquila* are two small constellations that don't contain very bright stars, but are easily located and not easily forgotten. They are *Sagitta* (sah-GEE-tah) the arrow — another constellation that bears a striking resemblance to the object it stands for — and *Delphinus* (del-FEE-nus) the dolphin. Delphinus looks like a small diamond with a one-star appendage; the group is also known as "Job's Coffin".

We've saved for last the one feature of the summertime sky that may well leave the longest lasting impression — not a constellation, but the magnificent *Milky Way*. The Milky Way is visible as a faint band of light in the winter sky, and is invisible to all but southern hemisphere observers in the spring. In the summer, however, the Milky Way stretches up from the southern horizon through Sagittarius, *Aquila* and Cygnus, until it disappears over the northeastern horizon. These huge clouds of stars are at their brightest in Sagittarius, where they rise from the spout of the teapot like a boiling cloud of steam. (In fact, the stars in the handle and lid of the teapot form another asterism called the *Milk Dipper* — so known because it looks like a pan about to scoop milk from the Way.) The Milky Way continues bright as it goes north; the Cygnus starcloud runs right down the upright beam of the Northern Cross. You have to travel far from the lights of the city to see the Milky Way in all its glory, but once you do, you'll never forget it. There's nothing else in nature like it. Isn't it lucky that this glorious sight is visible during the summer, when the largest number of people are most likely to see it? 

Top left: Cygnus is plainly visible in this shot taken with a 35mm Ricoh Singlex using a 55mm lens at f/1.7 on 103aE film, and exposed for 20 seconds. Photograph by David Hudgins. Top right: Lyra peeps out of the stellar clutter in this four minute guided exposure on Tri-X film taken with a 35mm Pentax using a 28mm lens at f/3.5. Photograph by Alan Dyer. Bottom: These photographs (*Aquila* on the left and *Sagittarius* at right) were taken using the same procedure and timing. A Miranda Sensorex I camera with a 50mm Auto-Miranda lens at f/2.0 was used to make these 10 minute exposures on Tri-X-film. Photographs by Robert E. Gewin.

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Packing Charge: \$15.00
Shown with optional camera adapter



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Shown with optional Manual Declination Control, 2" Photo-Guide Telescope, VariGuide R.A. Drive Corrector and Accessory Shelf

COMPLETE REFLECTING TELESCOPES

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Model 618: 6" f/8 without Motor Drive	339.95
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Model 826: 8" f/6 with Motor Drive	489.95
Model 816: 8" f/6 without Motor Drive	429.95
Model 856: 8" f/6 with Motor Drive, 2" Photo-Guide Telescope, and VariGuide Dual-Axis Control System	770.00
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COMPLETE EQUATORIAL MOUNTS The same precision mounts used on Meade 600- and 800-Series reflecting telescopes. Each mount includes: ball bearing equatorial head, cradle rings, setting circles on both axes, pier, and tripod legs. Motor Drive models also include manual R.A. override control.

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variable correction rates, not just "ON-OFF". Models 40 and 41 may be used with any motor-drive-equipped telescope rated up to 10 watts, including most commercial telescopes to 12 1/2" aperture.

Model 40 — Operates from 12 volts D.C. Control box includes variable center-frequency settings for lunar, planetary, sidereal rates. **\$89.95 ppd.**

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11 - VariGuide Dual-Axis Corrector Systems — For the advanced astrophotographer. Universal joystick controllers permit continuously variable correction rates simultaneously on both telescope axes. Each unit includes electronic control systems for both R.A. and Declination, along with all required mounting hardware. Models are available to fit Meade 600- and 800-Series reflectors and for the Celestron 5 and 8, as noted. After 15 minutes' installation, you will be using the most sophisticated and precise guiding system ever offered the serious amateur.

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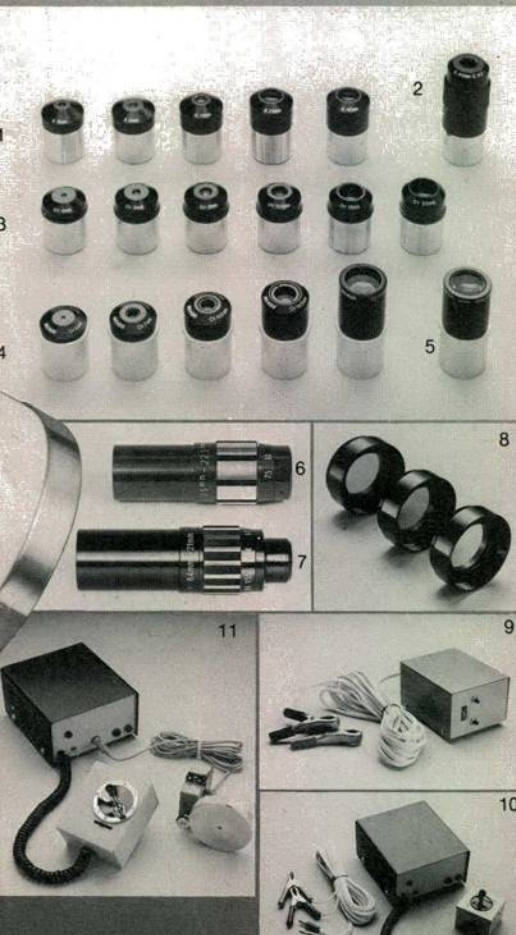
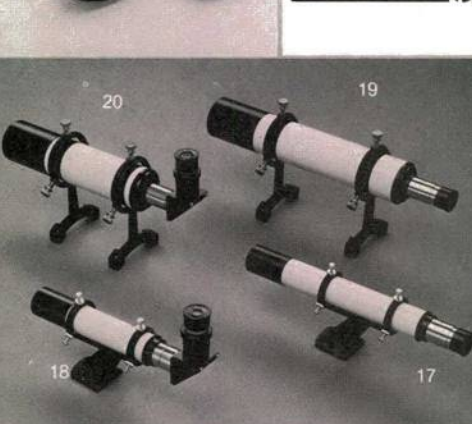
26 - Model #54 — 8" x 12" . . . **\$12.95 ppd.**

27 - ILLUMINATED RETICLE GUIDING EYEPIECE (1 1/4" or .965" O.D.) — For professional-level photographic guiding. Kellner 12mm optical system, with precisely focusable 4-line glass reticle. Remote brightness control and 3 ft. cable. (Extension cables available.) Complete . . . **\$44.95 ppd.**

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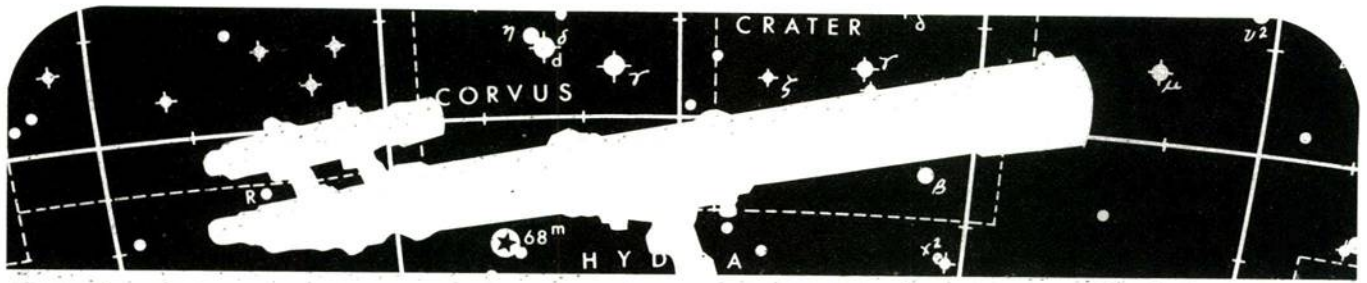
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EQUIPMENT ATLAS

What's Inside Your Telescope? Part 3: Catadioptrics

by

Robert E. Cox

In previous installments of "What's Inside Your Telescope?", we've found that a *catoptric* instrument is a reflecting (mirror) telescope, and a *dioptric* instrument is a refracting (lens) telescope. This month there will be no problem in knowing what form of instrument is being explored: Obviously a *catadioptric* is a telescope that uses both mirrors and lenses to form an image!

The marriage of the catoptric and dioptric systems led to offspring that possess the best characteristics of both: long focal length, no noticeable color aberration, and high resolution and definition in the image. In the Cassegrainian type, catadioptric telescope designs possess the compactness so vital to optical systems used in spacecraft. Indeed, it's no surprise to learn that most planetary probes have employed catadioptric objectives in the electronic cameras that record and send back pictures from space. Catadioptrics are truly modern space age instruments!

However, of the two most popular forms of catadioptric instruments, one dates back 48 years and the other 37. In both cases, they were presented originally as designs for fast cameras. The visual Cassegrainian types of telescopes derived from them were mentioned in the original patents, but not developed until later.

The Schmidt Design

The oldest of the designs — the Schmidt camera — was invented by Bernard Schmidt in 1930. One type of instrument needed by astronomers for research was a wide field fast photographic camera, and at that time, no satisfactory instrument was available. Schmidt's new invention fully satisfied these requirements.

The principle of Schmidt optics is shown on page 43. Light from a celestial object enters a small circular hole (the aperture) placed at the radius of a spherical mirror. It then strikes the spherical mirror which reflects it to a focus. Parallel rays of light from many stars all focus on a curved focal surface to yield small, high quality point images of the stars. However, such a system is photographically "slow". Fur-

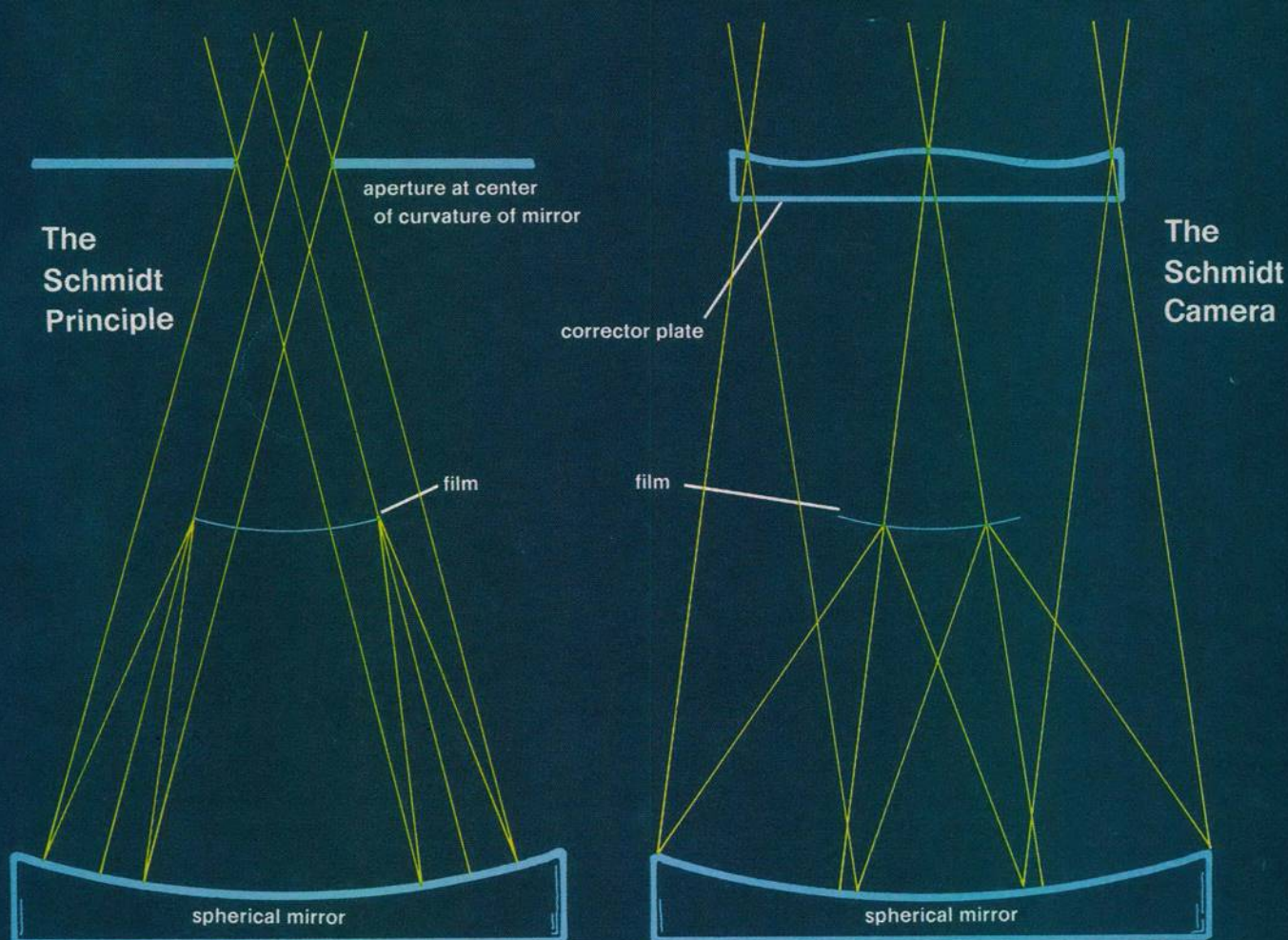
thermore, light losses incurred by the photographic film blocking incoming light render this system impractical; still, it shows promise. Let's explore it further.

The large mirror is an active, image forming element. The aperture is a passive element, acting as a stop, which allows the large mirror to perform properly. If this stop isn't in the correct place — at the center of curvature — the mirror won't yield good images over a large angle. The trick is to open the aperture wide without moving it. For astronomical work, as large an aperture as image quality will allow is needed, but when that is done, spherical aberration degrades the image quality.

Schmidt's invention utilized a large opening, but instead of having a stop, he substituted a special active lens. Using a highly distorted curved surface, this odd lens corrects spherical aberration. In the drawing on page 44, the general curve of this so-called "correcting plate" has been exaggerated. Such a lumpy element is referred to as an *aspheric* (meaning not spherical) surface. The lenslike action of the various curved areas of the plate creates an amount of spherical aberration *equal and opposite to that of the primary mirror*. Light rays that strike the large mirror then come to a perfect focus.

Although American astronomers were interested in Schmidt's invention, they found that professional opticians were not familiar with making such strongly deformed surfaces and were hesitant to undertake the task. Interestingly, the first Schmidt camera built in the United States was made by an amateur telescope maker, Dr. H. Page of Riverside, Calif. Yerkes Observatory had a Chicago hobbyist make their two original Schmidt cameras because they were unable to buy them from professional optical shops!

The method used by Schmidt to make the unusually shaped corrector plate was to work a deformed sheet of glass. He placed it over a special holder and partially evacuated the air, causing the glass to bend inward. The shallow, distorted concave surface was then ground and polished to a long spherical surface. Upon releasing the vacuum, the glass again became



Symmetry is the key to the Schmidt design; a lensless Schmidt covers a wide field because light entering the aperture always strikes the main mirror "on-axis". Spherical aberration limits the lensless Schmidt to small apertures. Using a special corrector lens to cancel the spherical aberration of the main mirror yields a nearly ideal astrocamera that covers a wide field with excellent images.

flat on the back, but its upper surface retained the desired aspheric shape. This method was dangerous if the glass broke during the grinding or polishing (which it often did), resulting in flying glass pieces that could cut the worker. Various other techniques developed by opticians were all slow and time consuming, making the production of Schmidt correcting plates far too expensive. Mass production was needed to make it practical to put these instruments on the market at a price reasonable for the hobbyist.

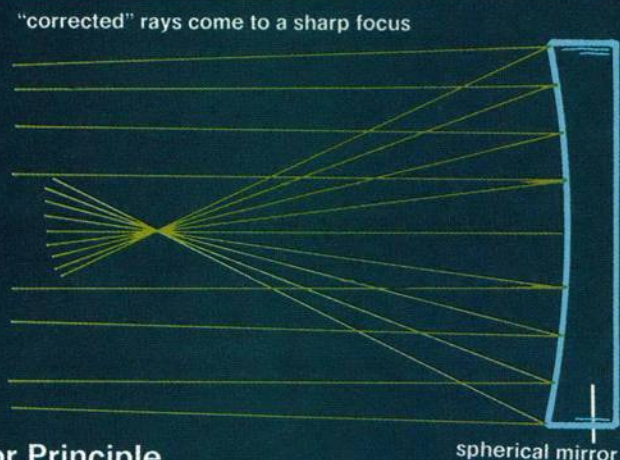
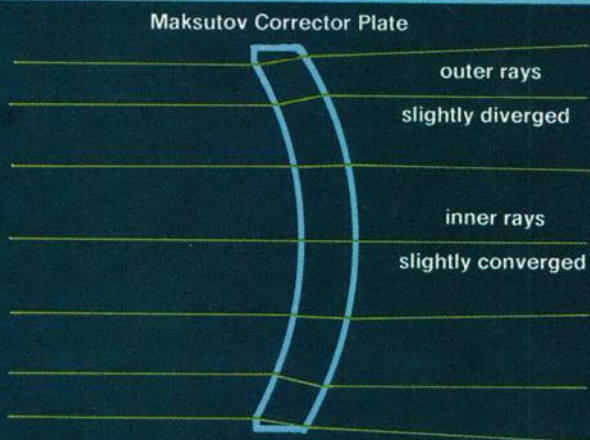
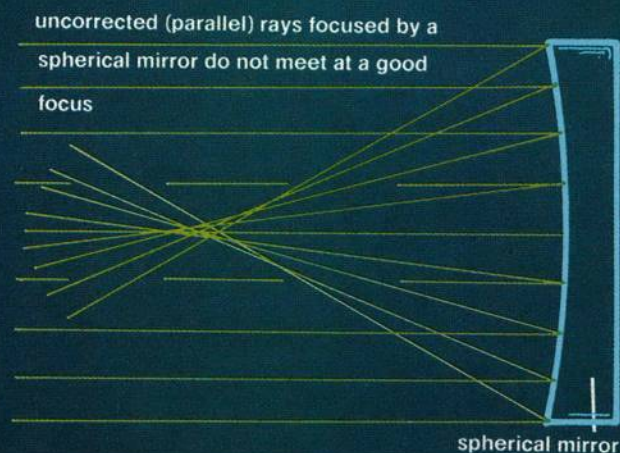
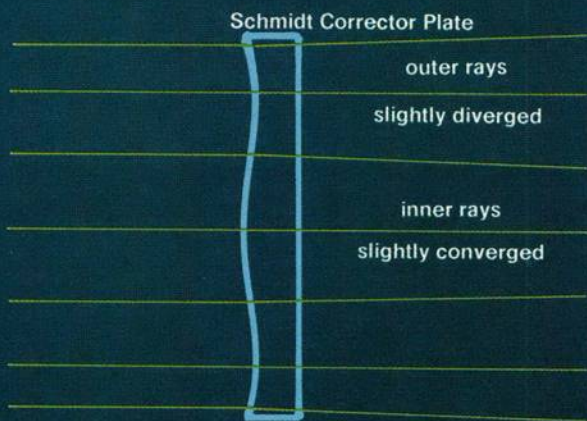
Today, because of the pioneering work of Thomas Johnson, founder of Celestron International, in mass production techniques for Schmidt correctors, and the later efforts of Criterion Manufacturing Company, you can now buy reasonably priced Schmidt-Cassegrain telescopes.

The Schmidt camera is a long device; its corrector and mirror are separated by twice the focal length of the primary mirror. Due to its strongly curved field, it isn't a practical visual instrument. For visual use, it became necessary to revise the original design by moving the corrector closer to the

primary mirror and placing a small, active convex mirror element inside the focal plane to reflect the light to a location behind the large mirror. By careful choice of the curvature of the convex mirror, and by appropriately increasing the depth of the deformed corrector, a highly corrected Cassegrainian form of instrument was possible (see the illustration on page 45). Being able to adjust the spacings and shapes of two mirrors and one special lens allows optical designers to realize fine definition, wide field, and high power in a compact, portable package.

Before leaving Schmidt telescopes, let's consider another variation of the basic design. So-called lensless Schmidt cameras omit the corrector lens, yielding a camera which—although not as perfect an instrument as one with a corrector—is still capable of securing fine pictures of the heavens. Instead of the ultrafast $f/1.5$ to $f/2$ system that is used for commercially made Schmidts, lensless Schmidts are slower: $f/5$. The lack of the corrector lens means the images suffer from spherical aberration, but not badly. Using a six inch aperture stop 60 inches from a nine inch spherical mirror yields star images on the camera focal plane (30 inches from the mirror) about 0.002 inches in diameter. Carefully guided films from such a camera should be capable of enlargements of 10 to 15 times before the print images become objectionably large.

The Coulter Optical Company (P.O. Box K,



The Corrector Principle

54121 Pinecrest Rd., Idyllwild, Calif. 92349) sells a lensless Schmidt kit that includes a finished coated mirror and plans for assembly. Information is available upon request from them.

The Maksutov Design

In 1941, D. D. Maksutov, a Russian optician, devised a way to eliminate the difficult aspheric corrector plate of the Schmidt and yet obtain an instrument having similar characteristics. He placed an active correcting lens between the focus and the center of curvature of the primary mirror (see the diagram on page 46). Maksutov's corrector is a thick glass element with one side that is toward the incoming light concave, and the opposite face convex. The thickness of the corrector is substantially greater than that of the Schmidt lens. This element acts as a long focus negative lens having the same amount of spherical aberration as the large primary mirror — but of the opposite sign — so the two aberrations cancel out to form an almost perfect image on a curved focal plane. Maksutov cameras similar to Schmidt cameras are quite feasible, but for some reason have been far more popular in Europe than in the U.S.

For a visual telescope, the corrector must be moved closer to the large primary mirror to increase its optical power. Also, a convex secondary mirror must be added to the design to produce a Cassegrainian design. The actual optical power of corrector lens-

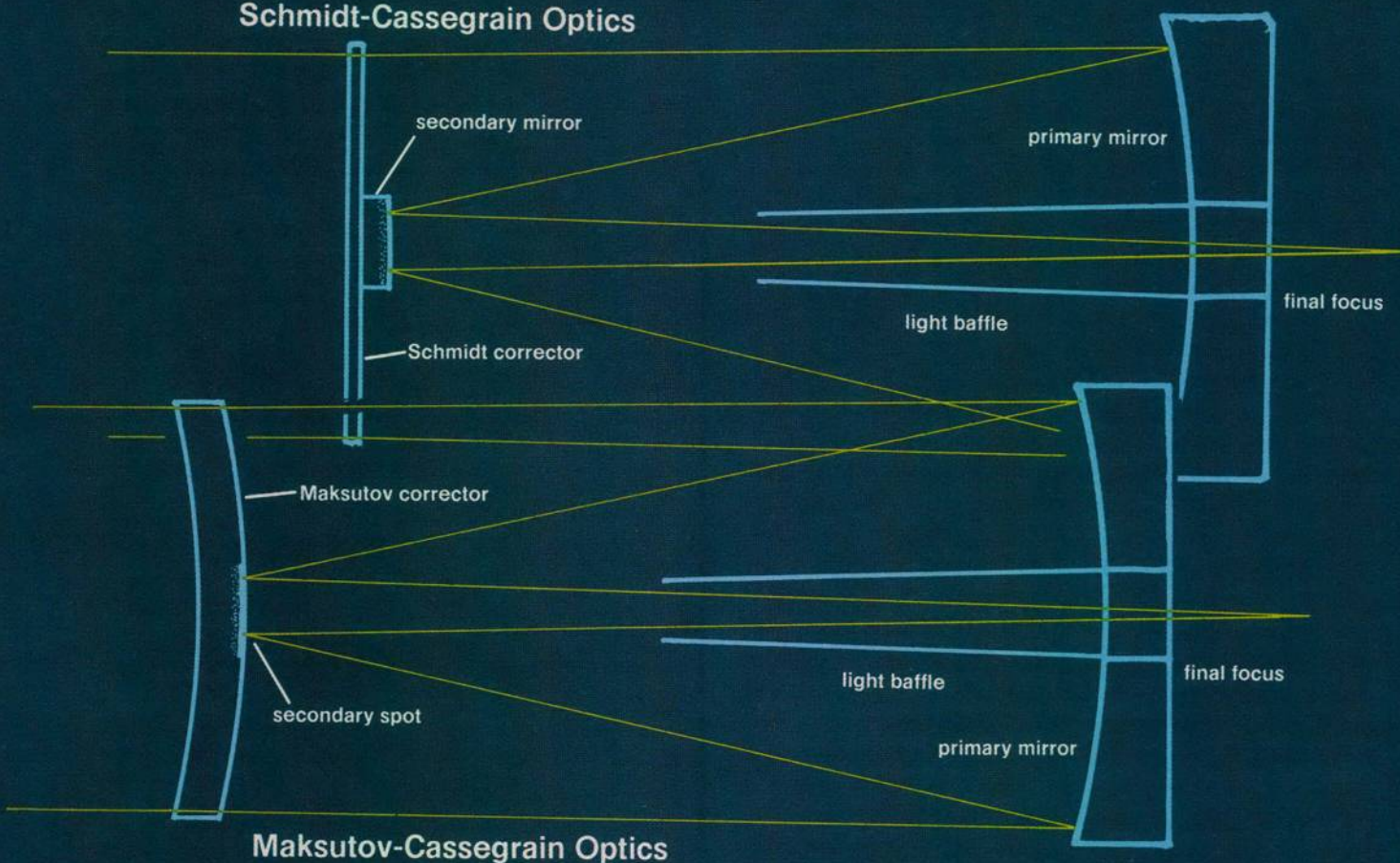
A spherical mirror suffers from "spherical aberration" — an inability to bring parallel rays of light to a perfect focus. Optical designers sometimes employ "correcting plates"—glass lenses that compensate for the errors of a spherical mirror to overcome the problem. Schmidt correctors have a complex curve on one surface to make the correction, while Maksutov correctors use a thick, strongly curved lens to accomplish the compensation.

es is generally very small; for example, a six inch $f/15$ (90 inch focus) instrument that has corrector radii $6\frac{1}{2}$ and $6\frac{7}{8}$ inches on its faces has a net focal length of ~ 747 inches! For the secondary mirror, it's general practice to use part of the surface of the corrector (as shown on page 45); making the corrector lens automatically also makes the corrector and secondary mirror. An advantage of this trick is that the secondary can't shift during transportation of the telescope, with a resultant loss of alignment. These instruments generally maintain better alignment than the Schmidt-Cassegrains previously described.

There is a special Maksutov design on the market: the Questar. It has its secondary spot coated on the *concave* surface of the correcting shell. The light makes a triple passage through the lens, and the result is a high quality instrument of high definition.

At present there is no Maksutov instrument on the market that uses the Newtonian form of design. Back in the mid-1960s, however, there was a fine telescope with the basic optics of an $f/4$ Maksutov-

Schmidt-Cassegrain Optics



Schmidt- and Maksutov-Cassegrain telescopes offer long focal length and large aperture in a compact housing. With the Schmidt, the secondary mirror is usually attached to the corrector plate; in the Maksutov, the secondary mirror is often an aluminized spot on the corrector lens — certainly an elegant design feature! Both types of telescope can be made in a wide range of sizes and focal ratios by an advanced telescope maker, and both designs are available on the commercial market.

Newtonian. With a three power Barlow lens, it became a high power $f/12$ system.

Advantages and Disadvantages of Catadioptrics

One of the pleasing qualities of catadioptric telescopes (also shared by any reflecting system with a window supporting the secondary optics) is the lack of "spikes" on bright stars when there is no supporting structure needed for the secondary. However, the size of the secondary mirror is larger than in an ordinary Newtonian telescope, which causes some loss in the definition of catadioptrics. Fortunately this is not serious enough to prevent seeing details in the various belts of Jupiter or in Saturn's rings or similar objects. The convenience of portability and ease of operation more than offset any effect of the over-size secondary.

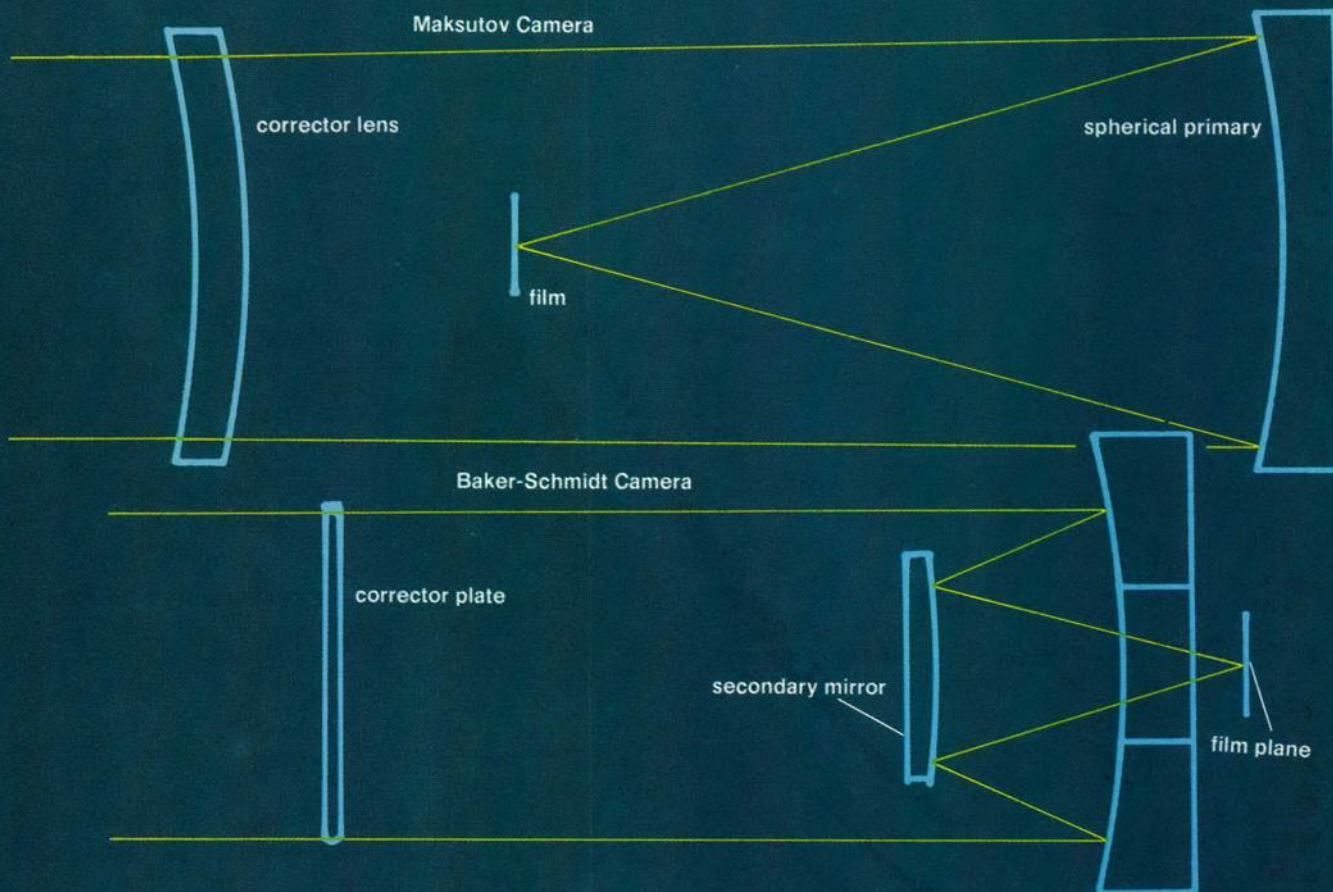
There are drawbacks to catadioptric systems, but then no design is perfect for all types of observations; each operates best for some specific type. Catadioptric telescopes are high power ones. They operate at $f/10$ or longer focal ratios. The small field

can be enlarged by adding an achromatic positive lens just behind the primary mirror. This speeds up the system for photography of extended deep sky objects, but degrades sharpness noticeably.

To help keep dew from depositing on the large corrector lens and ruining your observations, you need a dewcap — an extra bit of tube extending well past the corrector. Never wipe a dewed corrector with a cloth; rather, allow the moisture to evaporate. A little breeze of heated air helps. A *windshield hand defroster* gently applied from a distance will warm the glass surface and remove the dew, but won't heat the optic enough to spoil definition.

Don't let heavy dew deposit on the corrector. It can leak around the edge of the lens and dirty the inside surface of the corrector. If this happens, the corrector should be removed from the tube and cleaned on its inside surface. Since this is a job for a person experienced in dismantling and handling such optics, it's easier to avoid the dew!

Although a dewcap can help limit dewing on a lens surface when the telescope is pointed between the horizon and a point about 60 degrees above the horizon, at high angles and straight overhead, a dewcap will be of little help. Heated dewcaps can help control this problem, but finding the balance between controlling dew and still not causing disturbing air currents is a delicate state of affairs.



In extremely cold weather, the time it takes for catadioptrics to reach equilibrium when taken out is long, because they're sealed systems. If compared with a Newtonian, you'll find that the Newtonian will reach a condition of good seeing faster. Unless you have a full aperture type solar filter, you'll find the heat that builds up inside the sealed tube will quickly spoil your solar observing. Although the corrector is far enough inside the primary focus so heat of a dangerous level will not be concentrated on the lens if the image is displaced partly off the secondary, it's best not to use an unfiltered catadioptric on the sun at any time.

In winter months, Schmidt-Cassegrains show a plume of hot air coming off the metal secondary mirror support. Until this condition stabilizes, the quality of the image is inferior to a stabilized instrument. This is where a Maksutov (which does not have a metal cell to support its secondary) has an advantage. The thin aluminum Maksutov reflecting coat on the correcting shell stabilizes almost at once to match the glass upon which it is deposited.

In either the Schmidt or Maksutov instruments, it's possible to detach the secondary mirror from the corrector to place it freely between the primary and corrector. This enables the optical designer to have more freedom in correcting the system. The result usually has an even larger secondary obstruction than in a standard visual system — a secondary half the

size of the primary is not unusual, but these instruments are photographic. Baker-Schmidt designs can be very fast, and have a wide, flat field with excellent images everywhere. To support the separated secondary optics, it's necessary to have a supporting structure in the light path.

Most of the mirror/lens telephoto lenses for 35mm cameras on the market are Maksutov designs. Because of their speed — often f/8 or greater — it's necessary to place correcting lens elements between the secondary mirror and the final focus. Most are designed for use with film; they don't turn out to be satisfactory telescopes if you try to adapt them to use with an eyepiece. Exceptions are the Questar and Celestron Schmidt-Cassegrainian telephoto assemblies, sold to operate on 35mm and 70mm cameras.

Editor's Note: Our next installment of "What's Inside Your Telescope?" will be concerned with instruments that are not commercially available. These are the special designs made only in the workshops of telescope making enthusiasts. 🐞

Celestial Software

Part 2: Telling Time

by
Richard Berry

Humans measure time by counting repetitive events — the swing of a pendulum, the rotation of Earth, the moon's phases, or the oscillations of quartz crystal. In astronomy, time is fundamental because so many timekeeping methods are — or were — based on astronomical events. Our years, months and days are simply counts of astronomical events — so many revolutions about the sun, so many new moons, so many sunrises — whether we count them on a notched stick, tie knots in a string, or enter them into a computer. Hours, minutes and seconds are counts of a faster device, usually manmade — the swing of a balance wheel in a watch, the swing of voltage in a digital clock — with 60 seconds to a minute, 3,600 seconds to the hour, 86,400 seconds to the day.

The Equation of Time

(subtract from sundial reading to
obtain mean time*)

January 2 -4	August 4 -6
6 -6	17 -4
12 -8	25 -2
17 -10	September 1 0
25 -12	7 +2
February 6 -14	13 +4
12 -14 ^{m17s}	18 +6
18 -14	24 +8
March 4 -12	30 +10
11 -10	October 7 +12
19 -8	14 +14
25 -6	26 +16
31 -4	November 2 +16 ^{m23s}
April 7 -2	11 +16
15 0	21 +14
25 +2	28 +12
May 15 +3 ^{m44s}	December 3 +10
June 3 +2	9 +8
14 0	13 +6
23 -2	17 +4
July 2 -4	21 +2
17 -6	25 0
26 -6 ^{m27s}	29 -2

*remember that subtracting a negative number means you add the value

Measuring time wouldn't be difficult if we didn't mind inaccurate timekeepers; basic primitive timekeeping is enough to run our daily affairs. But accurate timekeeping, beginning in the 1600s with pendulum clocks, made more accurate and more complicated timekeeping not only possible but, for today's world, necessary.

The basic unit of time is the day, which is measured by counting successive crossings of the sky by an astronomical object — more precisely, by counting from the instant of one transit (that is, crossing of the meridian) to the next. You can build a sundial to do this, or note the moment that a shaft of sunlight falls across a line or the shadow of a pole crosses a fixed mark on the ground. The type of day you'll measure is called an *apparent solar day*. A very pleasant culture can easily function with this simple kind of day. If, however, you build railroads and sail ships around the world, you'll need clocks accurate enough to show that apparent solar time is not constant: Sometimes the days are too long, and sometimes too short. The errors can amount to nearly 15 minutes.

Mean Solar Time

The problem is that Earth's orbit is not perfectly circular and Earth's spin is tipped relative to the orbit; thus, the sun moves across the background of stars at an uneven rate, lagging as it moves far north or south of the equator. A kind of day called a *mean solar day* ("mean" means "average" here) is defined by an imaginary "mean" sun moving at a perfectly uniform rate across the sky. The difference between the mean sun's position and the real sun's position can be calculated and engraved on sundials to allow sundial users to convert sundial time into mean solar time. The correction is called the Equation of Time:

$$\text{Equation of Time} = \text{Apparent Solar Time} - \text{Mean Solar Time}$$

Thus, if you have a sundial, you can find the mean time by subtracting the equation of time from the sundial time (see the table on this page).

But mean solar time alone is not adequate for running a railroad. Time measured with a sundial (or corrected from a sundial) is *local time*. The sun shines on a spinning Earth; in some places it is noon,

Sidereal Time at 0 hours U.T.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	6:41	8:43	10:34	12:36	14:34	16:36	18:35	20:37	22:39	0:37	2:40	4:38
2	6:45	8:47	10:38	12:40	14:38	16:40	18:39	20:41	22:43	0:41	2:44	4:42
3	6:49	8:51	10:42	12:44	14:42	16:44	18:43	20:45	22:47	0:45	2:48	4:46
4	6:53	8:55	10:46	12:48	14:46	16:48	18:47	20:49	22:51	0:49	2:52	4:50
5	6:57	8:59	10:50	12:52	14:50	16:52	18:51	20:53	22:55	0:53	2:55	4:54
6	7:01	9:03	10:53	12:56	14:54	16:56	18:54	20:57	22:59	0:57	2:59	4:58
7	7:05	9:07	10:57	13:00	14:58	17:00	18:58	21:01	23:03	1:01	3:03	5:02
8	7:09	9:11	11:01	13:04	15:02	17:04	19:02	21:05	23:07	1:05	3:07	5:06
9	7:13	9:15	11:05	13:08	15:06	17:08	19:06	21:09	23:11	1:09	3:11	5:10
10	7:17	9:19	11:09	13:11	15:10	17:12	19:10	21:12	23:15	1:13	3:15	5:13
11	7:21	9:23	11:13	13:15	15:14	17:16	19:14	21:16	23:19	1:17	3:19	5:17
12	7:25	9:27	11:17	13:19	15:18	17:20	19:18	21:20	23:23	1:21	3:23	5:21
13	7:28	9:31	11:21	13:23	15:22	17:24	19:22	21:24	23:27	1:25	3:27	5:25
14	7:32	9:35	11:25	13:27	15:26	17:28	19:26	21:28	23:30	1:29	3:31	5:29
15	7:36	9:39	11:29	13:31	15:29	17:32	19:30	21:32	23:34	1:33	3:35	5:33
16	7:40	9:43	11:33	13:35	15:33	17:36	19:34	21:36	23:38	1:37	3:39	5:37
17	7:44	9:46	11:37	13:39	15:37	17:40	19:38	21:40	23:42	1:41	3:43	5:41
18	7:48	9:50	11:41	13:43	15:41	17:44	19:42	21:44	23:46	1:45	3:47	5:45
19	7:52	9:54	11:45	13:47	15:45	17:47	19:46	21:48	23:50	1:48	3:51	5:49
20	7:56	9:58	11:49	13:51	15:49	17:51	19:50	21:52	23:54	1:52	3:55	5:53
21	8:00	10:02	11:53	13:55	15:53	17:55	19:54	21:56	23:58	1:56	3:59	5:57
22	8:04	10:06	11:57	13:59	15:57	17:59	19:58	22:00	0:02	2:00	4:03	6:01
23	8:08	10:10	12:01	14:03	16:01	18:03	20:02	22:04	0:06	2:04	4:06	6:05
24	8:12	10:14	12:04	14:07	16:05	18:07	20:05	22:08	0:10	2:08	4:10	6:09
25	8:16	10:18	12:08	14:11	16:09	18:11	20:09	22:12	0:14	2:12	4:14	6:13
26	8:20	10:22	12:12	14:15	16:13	18:15	20:13	22:16	0:18	2:16	4:18	6:17
27	8:24	10:26	12:16	14:19	16:17	18:19	20:17	22:20	0:22	2:20	4:22	6:20
28	8:28	10:30	12:20	14:22	16:21	18:23	20:21	22:23	0:26	2:24	4:26	6:24
29	8:32		12:24	14:26	16:25	18:27	20:25	22:27	0:30	2:28	4:30	6:28
30	8:36		12:28	14:30	16:29	18:31	20:29	22:31	0:34	2:32	4:34	6:32
31	8:40		12:32		16:33		20:33	22:35		2:36		6:36

while at other places it is sunrise, sunset or midnight. When the sun will cross the meridian, and the local time, depend on the longitude of the place. The farther east you go, the earlier noon occurs; the farther west you go, the later noon occurs. Covered wagon travel never depended on accurate schedules, nor did the Pony Express really run on time. Railroads did. Before standard time zones were introduced, every town ran on its own time — each mile west meant setting watches back another five seconds! After standard time zones were introduced, only three clock changes were needed when crossing the width of the American continent. Each 15 degrees longitude farther west (1/24 of the full 360 degrees of longitude) set its clocks back a full hour.

Universal Time

The zero point of the world time system is in Greenwich (gren-itch), England. Zero longitude passes through the site of the old Royal Greenwich Observatory. Greenwich local mean time is not only the time in Greenwich, but also the world basis of time measurement, called *universal time*. Observers throughout the world record observations in universal time because they can be compared quickly without conversion. Throughout the world, almanacs are published in universal time because everybody uses it. Universal time is easy to calculate:

Universal Time	= Eastern Standard Time + 5 hours
Universal Time	= Eastern Daylight Time + 4 hours
Universal Time	= Central Standard Time + 6 hours
Universal Time	= Central Daylight Time + 5 hours
Universal Time	= Mountain Standard Time + 7 hours
Universal Time	= Mountain Daylight Time + 6 hours
Universal Time	= Pacific Standard Time + 8 hours
Universal Time	= Pacific Daylight Time + 7 hours

Universal time is always ahead of times in the United States. You'll notice that when the universal time day begins at midnight in Greenwich, it will still be evening of the *previous* day in New York, Chicago, Dallas, Denver and San Francisco. In each of these cities the populace will be following their own time zone clocks. For astronomers, however, the new day has begun, and all their clocks are set to read universal time. So are the clocks of astronomers in Europe, South America, Central Asia, Australia and Africa. All use and work with the same universal time.

Dividing the Day

The day must be subdivided before it is useful to us. "Many moons ago . . ." is not precise enough; we want to know that on June 4 at 3 hours 24 minutes 39.56 seconds, something will happen! In the past, hours were measured by noting the passage of the sun's shadow past markers, the burning of a marked

Sidereal Time Correction

U.T.	Add Correction	U.T.	Add Correction	U.T.	Add Correction
0 ^h 00 ^m	0 ^m 00 ^s	8 ^h 00 ^m	1 ^m 19 ^s	16 ^h 00 ^m	2 ^m 38 ^s
1 ^h 00 ^m	0 ^m 10 ^s	9 ^h 00 ^m	1 ^m 29 ^s	17 ^h 00 ^m	2 ^m 48 ^s
2 ^h 00 ^m	0 ^m 20 ^s	10 ^h 00 ^m	1 ^m 39 ^s	18 ^h 00 ^m	2 ^m 57 ^s
3 ^h 00 ^m	0 ^m 30 ^s	11 ^h 00 ^m	1 ^m 48 ^s	19 ^h 00 ^m	3 ^m 07 ^s
4 ^h 00 ^m	0 ^m 39 ^s	12 ^h 00 ^m	1 ^m 58 ^s	20 ^h 00 ^m	3 ^m 17 ^s
5 ^h 00 ^m	0 ^m 49 ^s	13 ^h 00 ^m	2 ^m 08 ^s	21 ^h 00 ^m	3 ^m 27 ^s
6 ^h 00 ^m	0 ^m 59 ^s	14 ^h 00 ^m	2 ^m 18 ^s	22 ^h 00 ^m	3 ^m 37 ^s
7 ^h 00 ^m	1 ^m 09 ^s	15 ^h 00 ^m	2 ^m 28 ^s	23 ^h 00 ^m	3 ^m 47 ^s

candle or the dripping of water, rather than the fundamental method of counting events. There simply aren't many reliable phenomena that repeat regularly at hourlong intervals. At shorter intervals, repetitive events abound: the beat of a heart, the swing of a hanging weight, the oscillation of a wheel mounted on springs. A swinging weight, such as a pendulum, is nearly ideal because it always swings at the same rate. It's easy to adjust the rate of swinging too: Simply move the weight up (faster) or down (slower) a small amount. The gears and dials of a clock are nothing more than mechanical counters adding up the beats of the pendulum, summing one (sometimes two) swing per second, 60 seconds per minute, 24 hours per day — 86,400 swings of the pendulum per day! Pendulum clocks were easily built to accuracies of a second per day and, by the 19th century, to a second per year.

Operating a master clock is not an easy job. Transits of the sun and stars must be timed and checked against long tedious computations of the expected mean solar time of transit. The clock must become a known quantity; it's difficult because its precise rate and errors are affected by temperature, air pressure, humidity and a hundred other more subtle influences. Astronomers' chief importance, until the 20th century, was the maintenance of time standards. Early in the 20th century, clocks finally became more accurate timekeepers than Earth's spin. Earth is slowly losing speed — the length of the day grows by about 1/1000 second per year. While it isn't much change, it isn't good enough for modern uses. The formal definition of a day is now based on the frequency of a laser (essentially by counting the oscillations of a lightwave) — some 600 trillion oscillations per second.

Sidereal Time

The sun is only one of the possible objects in the sky which can be used to count days. Stars cross the meridian every night too. The interval between the transit of a star one night and the transit the next night is a *sidereal* (from Latin for "star") *day*. Measured in the kind of hours, minutes and seconds obtained by subdividing a mean solar day into 24 hours, 1,440 minutes, or 86,400 seconds, a sidereal day is 23 hours 56 minutes 4 seconds long. So each

day (as measured in solar time), stars rise a bit earlier — 3 minutes 56 seconds earlier, in fact. By the end of a year, 366-1/4 sidereal days have passed while 365-1/4 solar days have passed.

Because sidereal time lags behind solar time in a predictable fashion, you can calculate the sidereal time if you know the universal time, your longitude, and the time of the year. Here's how to do it:

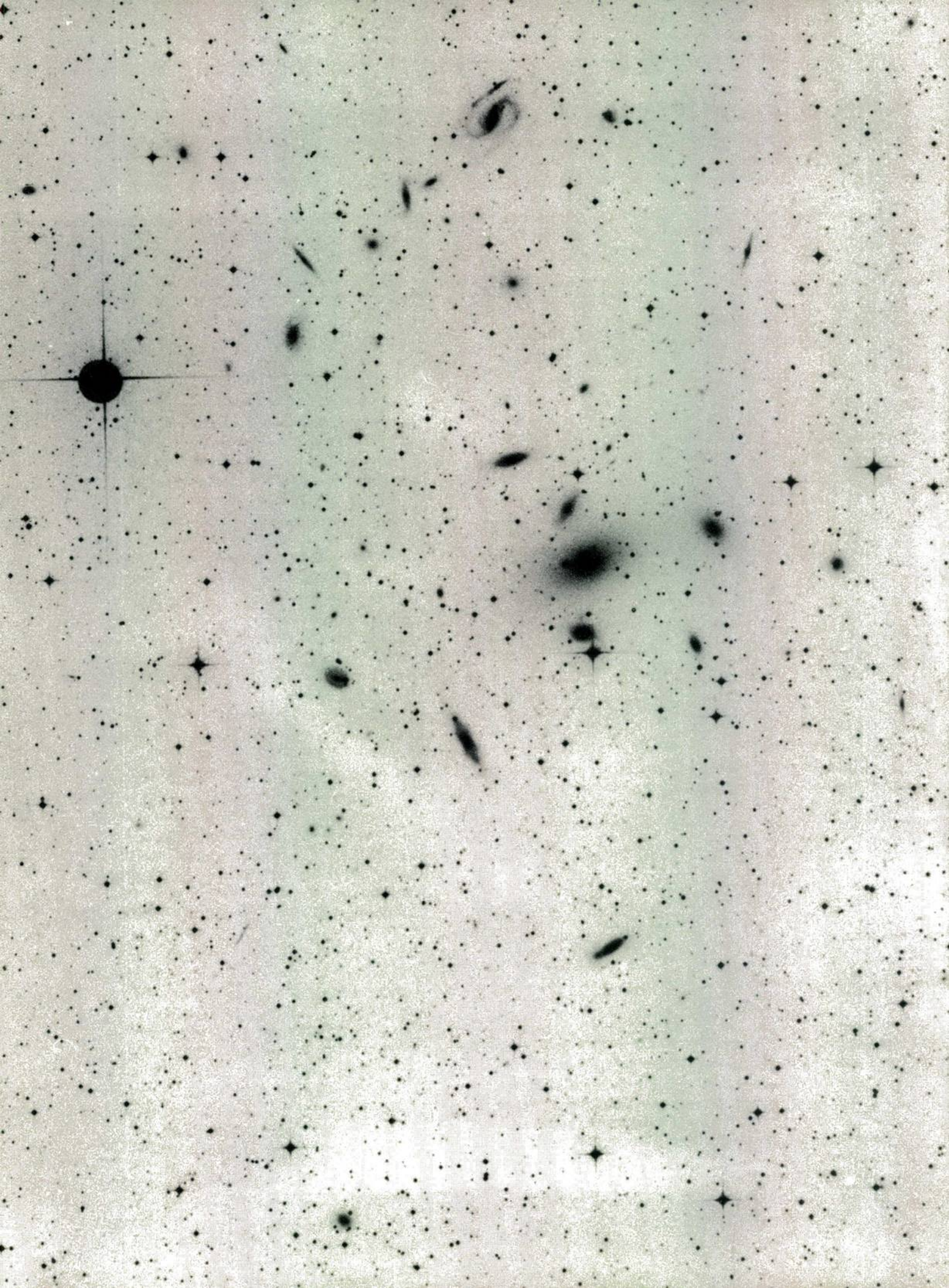
Step 1: Find your local mean solar time by subtracting one hour for each 15 degrees longitude west of Greenwich (longitude is shown on topographical maps and some good gas station maps). If you live 78°32' west of Greenwich, the correction is five hours for the 75 degree difference, plus 12 minutes for the remaining three degrees (one degree is equivalent to four minutes), plus four seconds for each 1' — $4 \times 32 = 128$ seconds, or 2 minutes 8 seconds. Your total correction is 5^h15^m8^s, which you must subtract from universal time. Since you live in the eastern time zone, already 5 hours behind universal time, you could also subtract 14 minutes 8 seconds from eastern standard time to find local mean solar time.

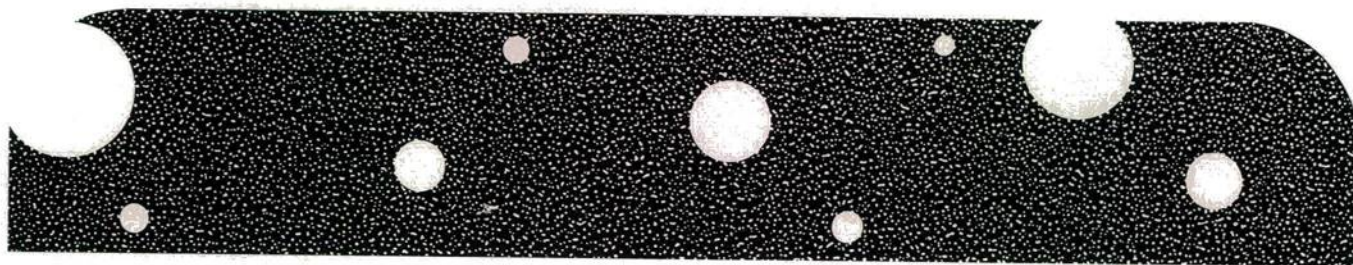
Step 2: Add the sidereal time correction (given in the table above). This table saves you some work; it shows the sidereal time in Greenwich each day at 0^h UT. You could calculate this yourself, but the table is accurate enough. (A more precise table appears each year in the **American Ephemeris and Nautical Almanac**.)

Step 3: Next add a small correction because the sidereal day is shorter than the solar day by about one part in 360. Divide universal time (your local mean solar time plus your time zone correction) by 360. This correction will be just a few minutes.

Step 4: If the sum of all these hours is greater than 24 hours, subtract 24 hours. (If it isn't, leave it alone). The result will be your local sidereal time, which is the right ascension of the stars on the meridian for the moment you've calculated. You can use the sidereal time with the setting circles on your telescope to find sky objects (see "Right Ascension and Declination" in the April 1978 issue). ☛

Editor's Note: There's more to time than just the time of day. Future articles will fill you in on how a year is measured, and what a month is all about!





STELLAR FRONTIERS

ARE GALAXIES HERE TO STAY?

by

Virginia Trimble and Martin Rees

Galaxies exist. Edwin P. Hubble settled this for most astronomers in 1923, when he identified Cepheid variables in the Andromeda and Triangulum spiral nebulae. He thereby established distances for the spirals that meant they must be enormous systems of stars rather like our own Milky Way galaxy. A typical galaxy contains some 200 billion visible stars. If we could collect a dollar from each star in our galaxy, it would pay off about half of our national debt!

Not only do galaxies exist, but in one sense we even understand why they exist. The average density in our universe is so low that, in the absence of concentrations of matter like galaxies, there would be no chance for stars to form, give birth to planets, or make the chemical elements necessary for life. Thus no living creatures could ever have evolved, and we would not be here to worry about astronomical problems.

In another sense, however, our understanding of how galaxies form and reach their present attractive appearances is in a rather primitive state. In fact, things have become worse in the last few years. Instead of a single, coherent picture, with only details remaining to be sorted out, astronomers now have two seemingly contradictory scenarios, and only the beginnings of a synthesis between them. But that synthesis has some attractive features, and may turn out to account for a large fraction of our observations of galaxies and clusters of galaxies without disagreeing with anything else we think we know. In other words, we may finally have hold of a reasonably good model of galaxy formation and evolution.

Observations

All the observations of galaxies that have been made in the past 50 years would (and do) fill hundreds of books. It would be unreasonable to expect one model, no matter how clever, to deal with them all.

In this negative print, we see a rich cluster of galaxies dominated by a giant elliptical galaxy, and filled with spiral galaxies, elliptical galaxies, a barred spiral and possibly some interacting galaxies. Astronomers make negative prints so that faint features (such as the extensive halo of stars around the giant elliptical galaxy) won't be lost in the printing process. This cluster lies in the southern constellation Pavo. Photograph courtesy of the UK Schmidt Telescope Unit of the Royal Observatory, Edinburgh.

Thus the first step is to decide what features of galaxies are important enough to try to account for. These will normally be the properties that many galaxies have in common, or that vary systematically from one class of galaxy or cluster to another.

First on our list of important galaxy properties must be the basic shapes: elliptical, irregular, barred and normal spirals. But even here we can introduce some simplification. Spirals, for instance, consist of two components: a *spheroidally shaped* (or halo) *distribution*, consisting of old stars only, and a much flatter *disc distribution* which includes the younger stars and gas (see diagram on page 53). An elliptical galaxy, on the other hand, has only a spheroidal component, very much like that in the spirals. Irregular galaxies have many things in common with the more disorganized discs. In addition, there seem to be transition objects — galaxies that could be either irregulars or spirals with lots of disc and little halo, and lenticular galaxies, that could be either very flat ellipticals or spirals without much disc. What we really need to account for are two kinds of components — spheroidal and dislike — which can occur in different proportions to make different kinds of galaxies.

The two kinds of components behave differently. Discs usually have spiral arms, and the faster the disc rotates the more conspicuous and gassy the arms. Most of their mass is in the form of visible stars and gas, and none of the stars has metal abundances much less than 10 percent of the solar value.

Spheroidal components rotate slowly or not at all, and although they can be somewhat flattened, their basic structure is radial. Both the density of stars and their average metal content decline smoothly from high values at the center to low values 10 to 20 thousand parsecs out into the halo. The outer parts of the halo are dominated by stars of very low mass (or something else that contributes a lot to the galaxy's gravity but hardly at all to its light). Far out in the halo, the metal abundance is always low, but it no longer varies systematically with the radius. Both spheroidal and disc components have systematic variations of color, mass-to-luminosity ratio, and other properties that are closely associated with the masses and compositions of their stars. For instance, other

Disk and halo structures occur alone and in various combinations. The disk may predominate as it does in NGC-2841 (top), or the disk may have a strong halo system at its center as in NGC-4594. Note the dust and absorbing material in the disk. Finally, the elliptical galaxy NGC-4486 shows only a halo component and no trace of disk structure. The halo is very extensive, probably extending beyond the boundaries of this picture. Hale Observatories photographs.

things being equal, the more massive a galaxy is, the redder it looks. The red color is not a result of redshifts, but indicates relatively high metal abundance — suggesting that massive galaxies are more successful than small ones in retaining gas that has been processed through supernovae, where metals are made.

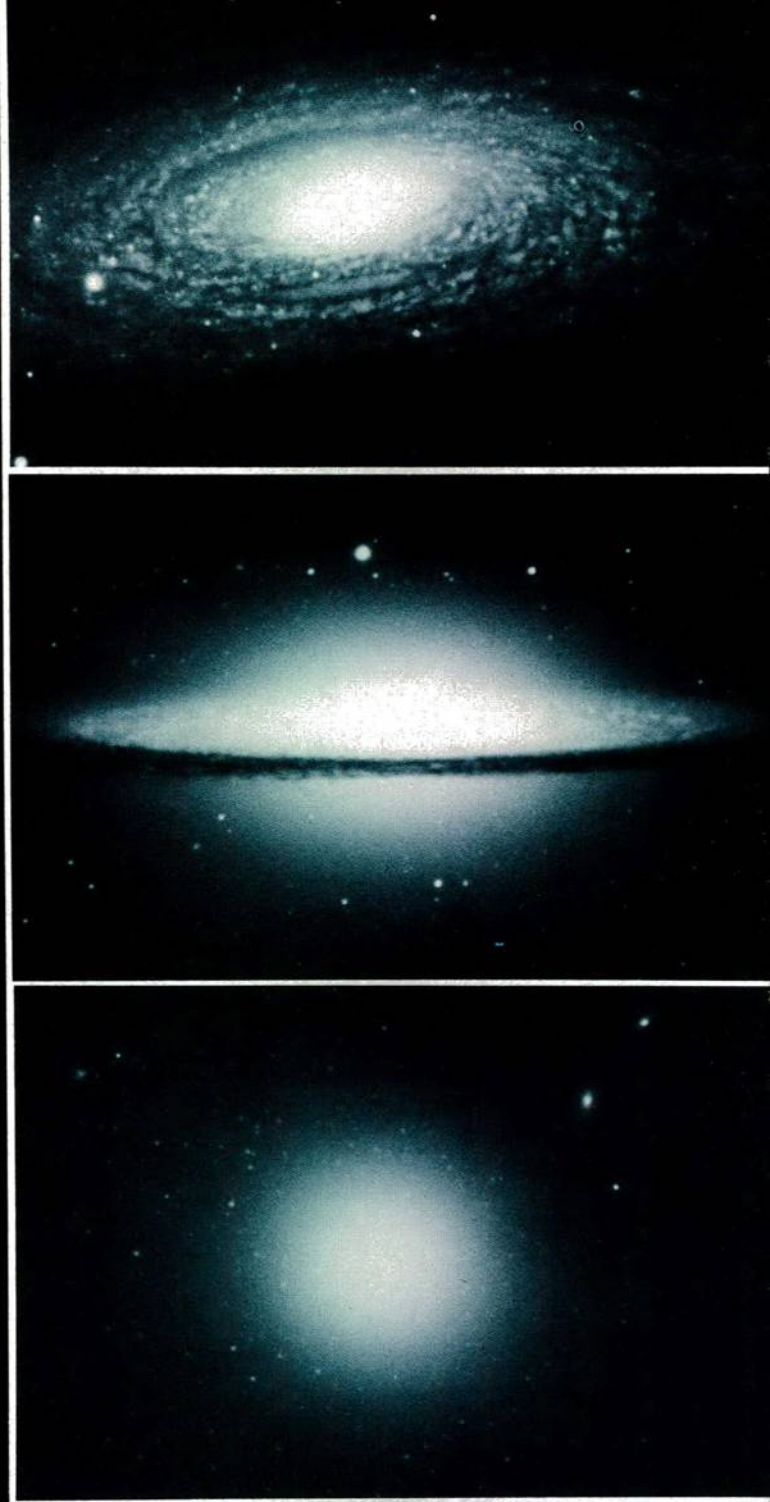
Galaxies “know” whether or not they are in clusters. Spirals, for example, are virtually absent from the middle of rich clusters. The gas has apparently been swept out of the galaxies and into the space between them. It can show up as part of a hot intra-cluster medium, whose x-ray emission reveals that the gas has an “almost solar” metal abundance. The central part of a cluster of galaxies also contains more than its fair share of the most massive galaxies — sometimes with an extrafat cD galaxy right at the center. A large fraction of a cluster’s mass is hidden in the intracluster medium, probably in the form of low mass stars, which have been stripped from the outer parts of galaxy halos.

Gas-Dynamical Models: The Conventional Wisdom

Our understanding of galaxy formation and evolution is changing so fast that the “clever new approach” of 1976 is the “reasonably coherent picture” of 1977 and the “outmoded convention” of 1978. For instance, the hope that astronomers may be able to understand galactic evolution quantitatively is so recent that a spot check of the indexes of 18 post-1972 elementary astronomy texts (the traditional repository of the parts of science astronomers think they agree about at a given time) uncovers only seven with any mention at all of galactic evolution. Most of these merely say that nothing is known about it. Under these circumstances, it’s a bit difficult to say what the conventional wisdom is. But if you’d asked a diligent reader-of-the-literature and attender-of-astronomical-conferences a couple of years ago to summarize what was known about the formation and evolution of galaxies, the result would have been something like the following:

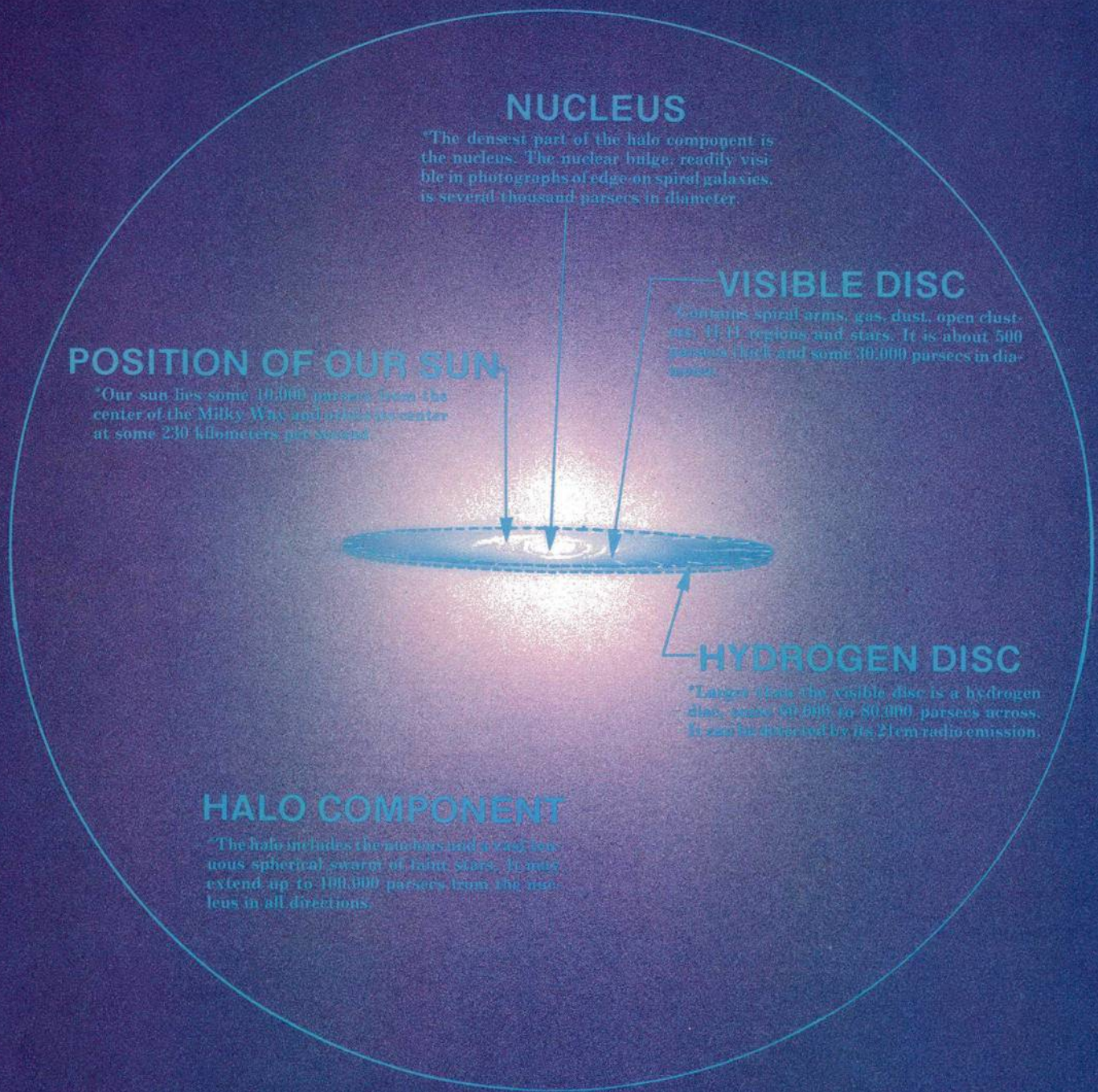
“The very early universe may have been exceedingly chaotic, because light and other kinds of energy had not had time to travel from one place to another and smooth things out. Chaotic temperature, density, and velocity variations were partially smoothed by diffusion of photons and neutrinos, but some ‘lumpiness’ would survive. When the expanding universe cooled to a temperature near 3,000 degrees Kelvin, protons and electrons combined to make neutral atoms. In that early era, the universe was a billion times denser than it is now — much denser than a present day galaxy or cluster.

“Although galaxies didn’t then exist, they must



have developed from lumps of above average density. The lumps that could most readily survive the smoothing had characteristic masses comparable to those of present groups and clusters of galaxies (10^{12} to 10^{15} solar masses). When the material in such a surviving lump discovered that it was gravitationally bound, it stopped expanding with the rest of the universe and began to contract. Since this couldn’t have happened until the average density of the universe had dropped to that in clusters now, contraction of clusters began about a billion years after the big bang expansion started.

The contracting surviving lumps were the proto-clusters. Within them, some regions had higher densities than others and served as nuclei onto which



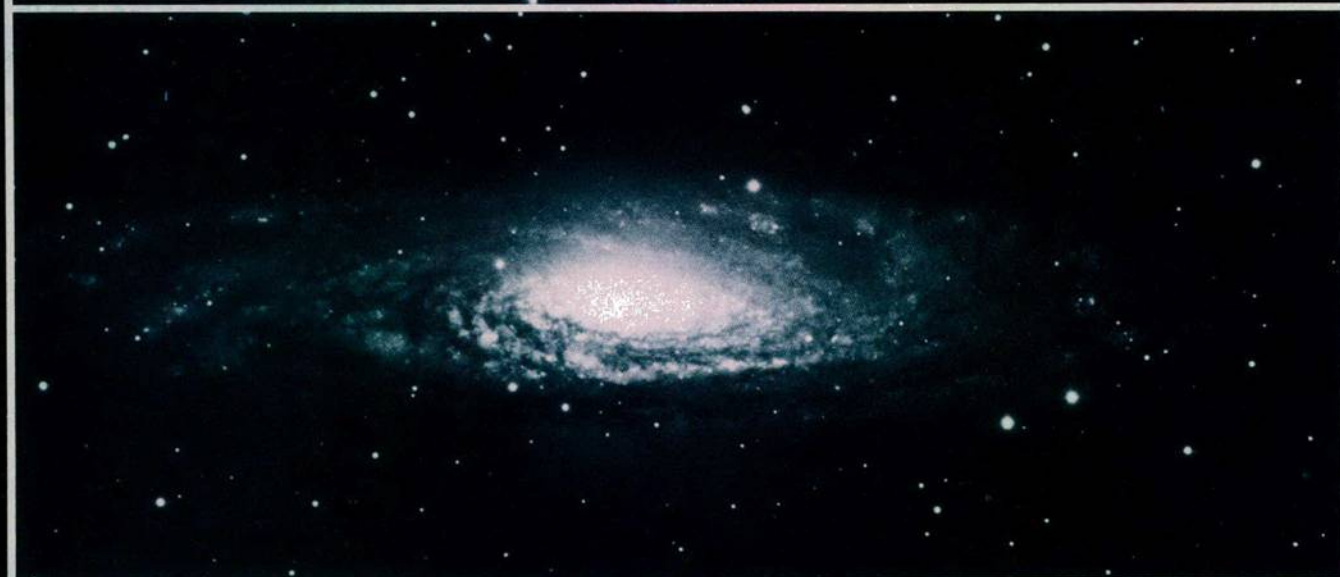
more gas condensed. After another billion years or so, each subcondensation had acquired most of the matter it would ever have, and thus deserved the name protogalaxy. Gas that never made it into a protogalaxy became the intracluster medium.

"What each protogalaxy did next depended on its mass, rotation, degree of turbulence, and perhaps some other things we don't know about yet. These in turn depended on the environment where the protogalaxy condensed, accounting for the fact that galaxies know where they are in clusters. All the protogalaxies were roughly spherical, and began to make stars quite promptly. Among the first stars were some very massive ones that turned a few hundredths

percent of the gas into metals, and then mixed it throughout the rest of the gas.

"Star formation in the lumps continued, making the stars we now see in spheroidal distributions. If all the gas managed to condense at this early stage (presumably because the lump had a small amount of rotation and turbulence), the galaxy became an elliptical. The subsequent evolution of ellipticals has been quite simple: Gas shed from the stars in supernovae, planetary nebulae and so forth, was lost to the galaxy if its mass was small and its gravity weak. Dwarf ellipticals were left with a single generation of aging, metal-poor stars.

"More massive galaxies had enough gravity to keep their metal-rich gas. Their gas clouds collided,



turning their energy of motion into heat which radiated away, allowing the gas to flow toward the center of the galaxy. As it flowed, it gradually condensed into new generations of metal-rich stars. Thus we see gradients of metal abundance, from low at the outside to high at the center, in the spheroidal components of galaxies. Spectacular fireworks were likely to occur when the last of the gas arrived suddenly at the center and rapidly turned into many stars or a single supermassive object (or black hole). Some theorists hope (and their calculations even suggest) that the result will look like a quasar.

"Inside the more rapidly rotating and turbulent lumps, most of the gas did not turn into star immediately. Instead, the gas clouds converted their random motion into heat and radiation, delaying star formation. Their initial rotation caused these lumps to spin into flat discs. Star formation went rather slowly in these discs, and furthermore was largely confined to spiral arms generated in the disc by gravitational instabilities.

"These spiral galaxies have a halo population too, consisting of old stars and sharing the gradients and other properties of ellipticals. But they also have a flattened component, where stars have formed continuously from the time the remaining gas collapsed to a disc to the present."

Computerized versions of this model seem to be a tremendous success. They can account for many of the observed color, composition and brightness differences among galaxies (and between different places within galaxies), without feeding too many assumptions into the program. They do *not* deal very well with the random composition variations in galactic halos, with the earliest production of heavy elements in protogalaxies, or with the high metal abundance seen in intracluster gas. There are a couple of other problems. In this picture, galaxy formation and heavy element production (that is, intensive formation of bright young stars) occur late enough that we might expect to see very bright young galaxies at moderate distances. No evidence for these has been found. In addition, these models do not discuss the cases where there is strong evidence for direct gravitational interaction between galaxies, as in the centers of rich clusters.

In this model, galaxies are essentially closed systems. At most they may have some of their gas swept out into the cluster, or receive a bit of gas that flows into a disc from a halo or intracluster medium late in its life. But apart from this, galaxies and clusters will maintain their identities for most of the age of the universe.

The disc component of a galaxy is remarkably flat. On this page, three galaxies show their disc component from different angles. At the top (NGC-628) we see the disc nearly face-on; the one in the middle (NGC-7331) from a fairly low angle, and at bottom (NGC-891), we see the disc almost exactly edge-on. Note that light from the nuclear bulge of NGC-7331 shines behind the spiral disc. Hale Observatories photographs.

Gravitational N-Body Models: The Computer Takes Over

Sir Isaac Newton solved the problem of two bodies moving under the force of their own gravity in several interesting cases, like the Earth-moon system, the sun-Earth system, and the Earth-apple system. This can be done with a sharp pencil on the back of an envelope. The minute you introduce a third body, things get much more complicated, and can only be solved in certain special cases. By the time you have a thousand or so bodies, the size of the required envelope back is roughly the capacity of the largest digital computers. Thus it is only quite recently that anyone has tackled the question: What happens if you plop down a bunch of small objects (for instance, small clusters of stars) in an expanding universe and let them all interact with each other via gravity?

The answer is a curious one: If someone will give you the clusters (of about 100 million solar masses each), then the formation of galaxies and clusters of galaxies takes care of itself! And the clusters made in the computer look very much like the ones we actually see in terms of numbers of members, where the massive galaxies are, and so forth.

Clearly, astronomers have the beginnings of a whole new way of trying to understand galaxy formation and evolution. Suppose that not long after the electrons and protons combined to form neutral hydrogen gas in the early universe, some of the lumps from the chaotic early universe began to fragment into stars. This could have happened long before the density of the universe had dropped low enough for proto-clusters to form. And it has several advantages. These very early stars will pollute all the rest of the gas with metals, so we are no longer surprised that intracluster gas is metal-rich. When pre-existing clusters interact to form galaxies, stars from a single cluster could end up almost anywhere in the new galaxy, so we are no longer surprised by composition variations in halos. And the interactions will continue right down to the present time, so that we expect to find galaxies in the process of capturing and assimilating each other, especially at the centers of rich clusters. And this is just where we find the overgrown cD galaxies.

But we have lost something. It's no longer easy to account for the systematic variations among galaxies, and with position in spheroidal components that the gas-dynamical models dealt with so well.

A Combined Model: This Year's "Best Buy" in Galaxy Evolution

By now you may well be way ahead of us — and already have asked the obvious next question: Since these two models are complementary, each dealing well with the phenomena that the other cannot account for, isn't there some way of combining the virtues of both? Clearly there is. We must consider both gas-dynamical and N-body processes.

The unified scenario starts, as usual, with a hot, dense early universe in which nuclear reactions turn



Globular clusters resemble, in mass and composition, pregalactic clusters that might have formed directly from eddies in the early universe. Globular clusters have a typical mass of 100,000,000 suns and are very old, dating back some 12 to 15 billion years. The globular shown here is M-13 (NGC-6205). Hale Observatories photograph.

Glossary

cD galaxy — A supergiant galaxy, with perhaps 10 times the mass and luminosity of a normal, large galaxy like our own Milky Way. They are normally found at the centers of rich clusters, and may have been formed by the collisions and mergers of many normal galaxies.

Cepheid variable — A star whose brightness changes by several magnitudes with a regular period. The length of that period (they range from about 10 to 60 days) is uniquely correlated with the absolute brightness of the star, so that such stars can be used to determine the distances to systems in which they occur.

Electron — A negatively charged particle found in the outer regions of atoms, orbiting the nucleus. In normal atoms, the number of electrons in orbit is equal to the number of protons in the nucleus, so that the atoms are electrically neutral. Atoms which have lost one or more of their electrons are called ionized.

Intracluster medium — Whatever is found between the visible galaxies in clusters. X-ray observations tell us it includes some metal-rich hot gas. There is also a large amount of invisible mass, perhaps in the form of very tiny, faint stars.

Mass/luminosity ratio — Also known as the mass to light ratio. The mass of a star, galaxy or cluster divided by its energy output. Both are measured in solar units; hence $M/L = 1$ for the sun. M/L is large for galax-

ies filled with nonluminous matter.

Metals — In astronomers' jargon, all the chemical elements except hydrogen and helium. They constitute about two percent of the mass of our sun, the interstellar gas and other relatively young objects, but only 0.1 percent or less of the oldest stars. More than half the mass of these heavy elements is made up of carbon, nitrogen and oxygen — non-metals to a chemist, but astronomers have historically called them metals because the most conspicuous spectral lines come from things like sodium, calcium and iron, which really are metallic.

Microwave background — Electromagnetic radiation (predominately at microwave wavelength) thought to be a relic of the early, hot dense phase of our universe. It has a temperature near three degrees Kelvin (implying temperatures of billions of degrees in the distant past), and very nearly the same intensity in all directions in space.

Neutrino — A particle that has no mass or charge, but carries energy and can interact with other particles only under rather special circumstances. An average neutrino could penetrate a light-year thick slab of solid lead before it was stopped.

Neutron — A particle found in atomic nuclei. Neutrons contribute only mass, and no charge. They are unstable in isolation in the laboratory, but existed free in the early universe, contributing to the formation of helium.

Parsec — The astronomer's standard unit of distance. It is the distance to an object which has a *parallax* of one second of arc (thus reflecting the fact that our fundamental distance scale in the universe derives from measured parallaxes), and is equal to about 3×10^{13} kilometers (or three light-years).

Photon — A particle of light, radio waves, x-rays or other electromagnetic radiation. The photon has no mass of its own, but can carry energy and protons in atoms that do have mass.

Protocluster — A cloud of gas which, according to some models, acquires its identity early in the history of the universe and eventually fragments and evolves into a cluster of galaxies.

Protogalaxy — A gravitationally bound cloud of gas and/or stars which will eventually evolve into a galaxy.

Proton — A positively charged particle found in the nuclei of atoms. A normal hydrogen nucleus consists simply of a single proton.

Solar luminosity — The amount of power emitted by the sun. The energy output of stars and galaxies is sometimes expressed in solar luminosities. It is equal to 4×10^{33} ergs per second, or 3×10^{23} horsepower.

Solar mass — The amount of matter in our sun. It is often used as a unit for expressing masses of stars and galaxies, and is equal to 2×10^{33} grams, or almost a million times the mass of our Earth.



about 1/4 the material into helium. Although the matter is cool enough for nuclei and electrons to combine and form ordinary atoms after about 10 million years, the formation of stars is inhibited for another 100 million years or so. During this period, even a few massive stars would ionize the gas enough to stop any further star formation. The first size scale on which anything interesting happens is the largest one, on which there are big density fluctuations left from the early chaotic universe. Thus, clouds of about 100 million solar masses collapse and fragment into stars first.

About 90 percent of the gas turns into stars at this stage. The stars include some very massive ones that evolve rapidly, explode as supernovae, and throw the metals they have made into the remaining gas. But much of the fragmentation continues down to the minimum possible lump size — about 0.01 solar mass. This depends on temperature. Such low mass stars have long lifespans, compared to the present age of the universe, and are so faint that we could not see even the ones in the halo of our own galaxy. They may not even undergo nuclear reactions.

The 100 million solar mass clusters are then the units that interact gravitationally, collide and eventually merge to form galaxy sized lumps. Close encounters between pregalaxies can give some of them significant amounts of rotation. When the pregalaxies have built up to large enough masses, their gra-

Above: At the heart of the rich Coma cluster of galaxies lies a massive elliptical galaxy. According to the composite "best buy" theory described in this article, 100 billion years from now only the swollen monster galaxy will remain, the rest of the galaxies in the cluster having been absorbed. **Above right:** Looking deep into space and far back in time, clusters of galaxies look much the same as they do today. But if we look still deeper into space, the gas dynamical model predicts that we'll see galaxies actually being formed. This faint cluster is in Pisces. Hale Observatories photographs.

vity becomes great enough that the remaining gas falls into them. It does not immediately form stars, because every time a gas cloud comes too close to a star in the pregalaxy, it gets torn apart. Only when the gas has fallen in quite far, so that its average density is high, can it make stars and metals. Thus the parts of galaxies that we normally see are formed by this later infall, which acts very much like galaxy formation on the gas-dynamical model and produces abundance gradients, disc, and so forth. The invisible massive and very extensive halos surrounding the luminous parts of galaxies are made from the faint first generation stars.

While the visible parts of galaxies are busily forming from accumulated gas, various gravitational processes continue to occur. They gradually build up small groups of galaxies (like our own Local Group) in which individual galaxies retain their massive halos, as well as rich clusters of galaxies, in which halos are stripped off and become the invisible dif-



fuse mass of the intracluster medium. In rich clusters, gas will also be swept back out of galaxies quite early, accounting for the absence of spirals. As the galaxies continue to interact, the most massive ones accumulate near cluster centers. They eventually merge, and "cannibalize" smaller neighbors to form giant cD galaxies.

Because these processes have acted over the entire history of the universe, the appearance of clusters and galaxies depends on when you look. If you had looked at the matter which now forms the Virgo cluster of galaxies when the universe was only a few hundred million years old, you would have seen characteristic units of about one billion small stars, quite different from the present 100 billion star galaxies. And an observer 100 billion years in the future will see only a single, enormous cD galaxy there, with stars spilling out of it on all sides, and not much else but a few outlying dwarf galaxies. Hence, our "best buy" model indicates that galaxies are not a permanent feature of the universe, but are only characteristic of the time we happen to live in.

Testing the Models

The "best buy" model appears to accommodate all the existing observations fairly well. Several additional tests should be possible in the future. For instance, in the gas-dynamical model, the protoclusters condensing some billions of years ago should introduce place-to-place variations in the microwave back-

ground radiation which has been knocking around the universe ever since the first few hot hours. But no such variations are to be expected if clusters are assembled from pre-existing stars and galaxies.

Similarly, hot protogalaxies or protoclusters would have emitted x-rays which we would see as small "hot spots" on the sky. These may be detectable from HEAO-B when it flies later this year, but would not be conspicuous according to the "best buy" model. Finally, if all the metals we now see were made after the galaxies formed, young galaxies, filled with hot young stars, must have been very bright. We should be able to see them — very distant, very redshifted — with suitable infrared devices in the next decade. No such bright phase is required in the combined model, since many of the metals were made before the galaxies existed.

Thus future observations by radio, x-ray and infrared astronomers should be able to answer the question: Are galaxies here to stay? 

Virginia Trimble is a native Californian who obtained her Ph.D in 1968 from the California Institute of Technology. Since then, she has done research on white dwarfs, supernovae, pulsars, x-ray sources, and nucleosynthesis. She shares appointments at the University of Maryland and the University of California with her husband, Joseph Weber, who is best known for his development of gravitational radiation detectors.

Dr. Martin Rees is a professor at Cambridge University in England, with interests in astrophysics and cosmology. He has worked at Caltech, Harvard, Princeton, and Sussex University in the United Kingdom. Rees is director of the Institute of Astronomy at Cambridge.

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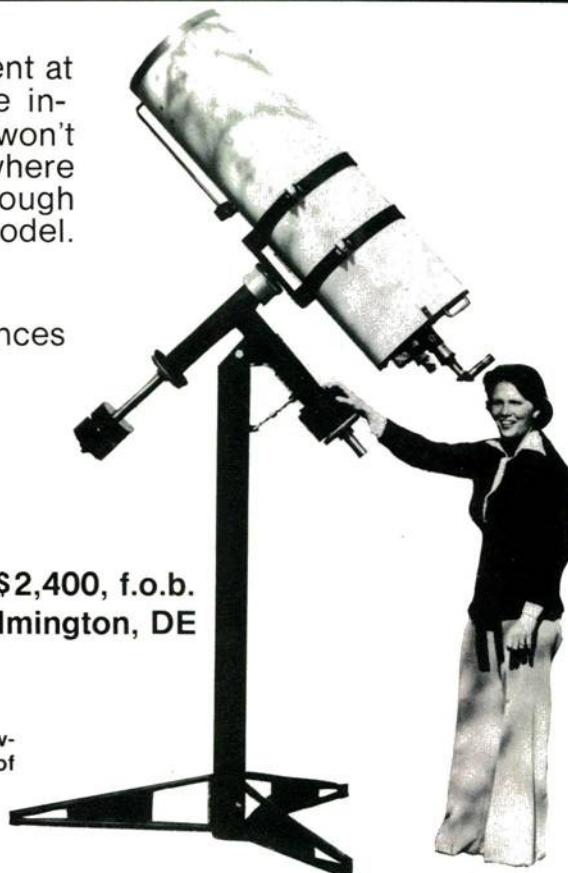
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ASTRO-NEWS

Latest News From the World of Astronomy

Observations Show New Rings Circling Uranus

Indications of four additional rings circling the planet Uranus, bringing the total to nine, have been confirmed by Caltech and Hale Observatories astronomers.

The observations were made on April 10 by Eric Persson of Hale Observatories using the 2.5 meter du Pont telescope at the Las Campanas Observatory in Chile. The additional rings had previously been observed on March 10, 1977 by James Elliot and others when the original discovery of the rings was made. Persson and his colleagues at Caltech (P. Nicholson, K. Matthews, P. Goldreich and G. Neugebauer) confirmed Elliot's findings concerning the four additional rings.

Normally the rings are too faint to be directly observed by telescope, but when there is an occultation, astronomers can measure how the light of the distant star blinks on and off as it passes *behind* the rings.

The star used for the new measurements was 100 times fainter than the star used in the original discovery. The astronomers were able to perform more sensitive measurements, however, by observing the star in the *infrared* region of the spectrum. At these wavelengths,

Uranus reflects little sunlight and thus appears extremely dark, allowing astronomers a more sensitive look at the star passing behind the faint, narrow rings.

One especially intriguing discovery was that the rings of Uranus have extremely sharp edges.

"It may be that the rings are defined by resonances with the moons of Uranus, which channel particles into tight ring patterns," Goldreich said. "Currently, the rings of Uranus must be classed only as fascinating curiosities," he said, "with only a hint that they may have broader implications for theories of the formation of planets and their satellites."

The rings of Uranus were originally discovered on March 10, 1977 by several independent groups of astronomers. The most definitive results were obtained by a team from Cornell University headed by Elliot. Five main rings were found, with radii ranging from 26,900 miles (44,800km) to 31,000 miles (51,700km), and widths from 1.8 to 60 miles (3 to 100km). The rings of Uranus are quite narrow compared to Saturn's rings, which measure about 30,000 miles

(50,000km) in width. All the Uranian rings lie in the same plane.

ASTRONOMY interviewed Brian Marsden of the Smithsonian Astrophysical Observatory concerning the rings of Uranus. According to Marsden, "The most interesting thing about the April 10 observation concerns Epsilon (the outermost ring). It's a lot thicker than we thought it was. We've known it's not a circle; the March 10 observations showed it to be an eccentric circle, an ellipse inclined to an angle. These new observations seem to suggest that the structure of Epsilon is quite complex. Basically it is intact (astronomers had predicted the ring was in partial arcs), but there are perturbations that may be caused by some unknown satellite."

"In terms of seconds of arc," Marsden continued, "Uranus' disk is two seconds, the Epsilon ring is four seconds, and Miranda (Uranus' innermost moon) is 10 seconds. I feel there might be another moon around five to six seconds of arc from the planet — probably six seconds is the best bet. Within five seconds is the Roche limit, so it would have to be outside of that. I'd be willing to bet there's a Miranda or Titania sized satellite around six seconds of arc. I would be very surprised if there aren't any satellites inside the orbit of Miranda."

Now that we know there are rings circling Saturn and Uranus, wouldn't it be reasonable to predict rings circling Neptune? Marsden thinks so. In fact, he and his colleagues, A.R. Klemola, William Liller and Elliot, published a paper in a recent issue of the *Astronomical Journal*, entitled "Predicted Occultations by Neptune". Using this information, astronomers may be able to take a closer look at Neptune specifically to see if there are indeed any rings circling it. According to Marsden, the best occultation for this year occurs on July 6, but the best one altogether will occur in 1980. ☛

Radii of the Rings of Uranus

Kappa	42,029km	25,217 miles
Iota	42,394km	25,436 miles
Theta	42,660km	25,596 miles
Alpha	44,835km	26,901 miles
Beta	45,788km	27,472 miles
Eta	47,290km	28,374 miles
Gamma	47,732km	28,639 miles
Delta	48,408km	29,044 miles
Epsilon	50,848km	30,508 miles

(The possible Zeta ring of J. Churms has not been confirmed, and there appear to be no confirmed rings of any consequence outside Epsilon. The information for this table was taken from the International Astronomical Union Circular No. 3215.)

Skylab's Back on the Books

NASA plans to turn the abandoned Skylab space station back on to keep it from re-entering Earth's atmosphere and breaking up before the Space Shuttle can rendezvous with it in late 1979 or 1980.

Meanwhile, two companies have been contracted by the space agency to study how the 85 ton (77 metric ton) orbital workshop might be reused.

Skylab was orbited in 1973 and used by three teams of astronauts, the last staying for 84 days and shutting the

space station down when they left in February 1974. Skylab's initial 273 mile (437km) high orbit has since deteriorated to 220 miles (352km). NASA is concerned that by the end of 1979 or early 1980 it will be down to 173 miles (277km), leaving it with just a few weeks before it finally plunges back to Earth. Estimates predict it would scatter debris over an area 100 miles (160km) wide and 1,000 miles (1,600km) long.

The accelerated decay has been blamed on increased sunspot activity. This

has heated the upper atmosphere, causing it to expand outward so that the air — even though still a good vacuum by Earth standards — is thicker at Skylab's altitude. The rate of decay is impossible to predict, though, because the solar activity is irregular, and because Skylab's complex shape makes it an aerodynamic nightmare.

Early in March, engineers at the Bermuda tracking station successfully awakened Skylab for a few minutes each day to check out onboard systems. Their first attempt was baffling when data they were receiving dropped out, and only the carrier wave came through. But they were able to work around this, and soon had two batteries on trickle charge to slowly rejuvenate them.

The Bermuda engineers managed to activate a computer in the Apollo telescope mount to transmit data, including the news that confirmed there is still pressure in the compressed nitrogen bottles used for attitude control.

NASA engineers hope to command Skylab into a slow tumble to reduce drag and slow orbital decay.

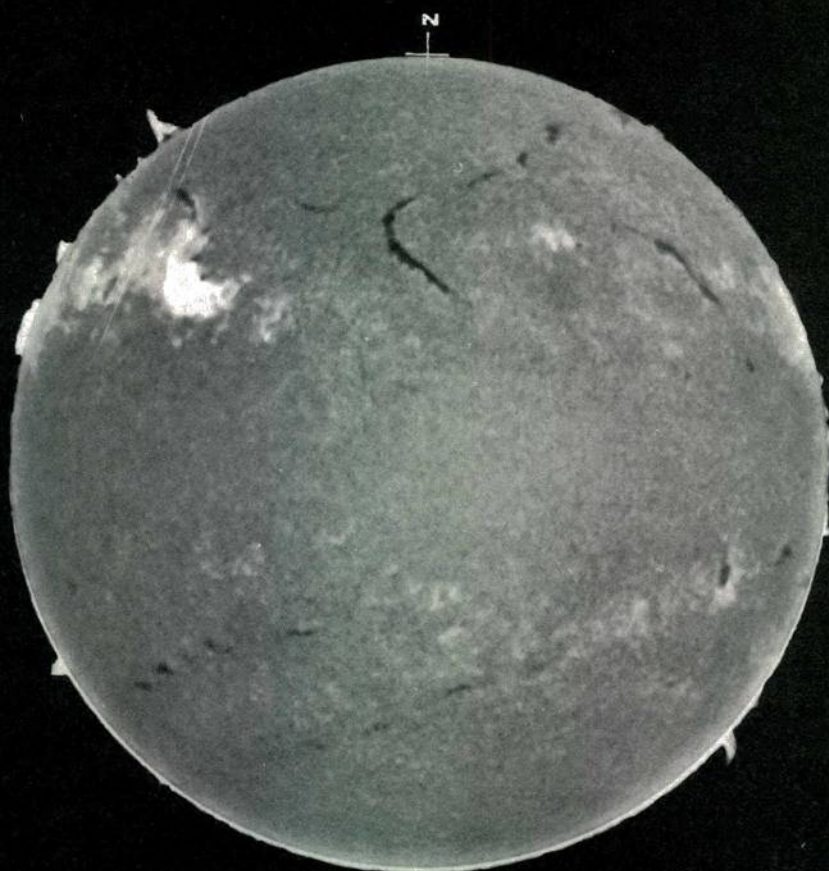
Present plans are for the third Space Shuttle mission (in late 1979) to rendezvous with Skylab and attach a miniature unmanned space tug called the teleoperator remote system (TRS). Its cluster of rocket engines will push Skylab into a higher orbit that should be good for 10 or more years. (The reboost plan is still in a tentative stage while NASA considers using the TRS to slow Skylab enough so that it re-enters Earth's atmosphere over the ocean.)

The TRS is being developed by Martin Marietta Corp. under a \$40 million contract. Martin Marietta is using equipment designed for the Viking Mars landers, Titan IIIC transtage, Skylab, Shuttle and other spacecraft. Only the structure is new.

Under \$250,000 contracts, Martin Marietta and McDonald Douglas Astronautics Corp. are studying the potential of reusing Skylab. Possible uses include refitting Skylab in orbit (it's too bulky for the Shuttle to return to Earth) for life as a more advanced space station, or to support operations with an attached Spacelab module.

Any reuse, though, will depend on the results when astronauts on a later Shuttle flight board Skylab and test its systems to see how much deterioration there has been since 1974. This probably would be done on the Shuttle mission that retrieves the TRS, assuming Skylab is reboosted. ☛

Solar Scorcher



On April 28, 1978, the largest solar flare in years was observed by the National Oceanic and Atmospheric Administration (NOAA). The solar observatory at Ramey Air Force Base in Puerto Rico reported that the flare had an intensity of four on a scale of one to four. The flare erupted on the eastern side of the solar disk (the large bright area at the left). The photo was made by NOAA's Space Environment Services Center in Boulder, Colo., using a telescope that views the sun in the red (alpha) line of the hydrogen spectrum which emphasizes flare-associated features on the sun. NOAA photograph.

Solar Activity Linked With Luminosity Drop

Our sun is a variable star. Since the onset of the new cycle of solar activity in 1977, its surface temperature has cooled by approximately six degrees Kelvin, equivalent to a drop in luminosity of 1/2 percent. This is the first time that a change in the sun's luminosity has been linked to changing solar activity.

This link was discovered by W.C. Livingston, an astronomer at Kitt Peak National Observatory. Livingston has been monitoring the sun's surface temperature since the last minimum in solar activity in the summer of 1975.

To make his measurements, Livingston used a spectroscopic technique which exploited the fact that the strength of the dark lines in the solar spectrum (the Fraunhofer lines) depends on the temperature of the sun's gases. He found the most reliable line to study was one due to carbon at a wavelength of 5,380 Angstroms, which gives temperatures to an accuracy of 0.15 degrees Kelvin. Temperature readings from the intensity of this absorption line were backed up with estimates from a nearby line in the sun's spectrum due to iron.

Livingston found the sun's surface temperature stayed constant to within one or two degrees for the first 1.5 years of monitoring. Then, as the new cycle of solar activity began in 1977, the temperature slump came.

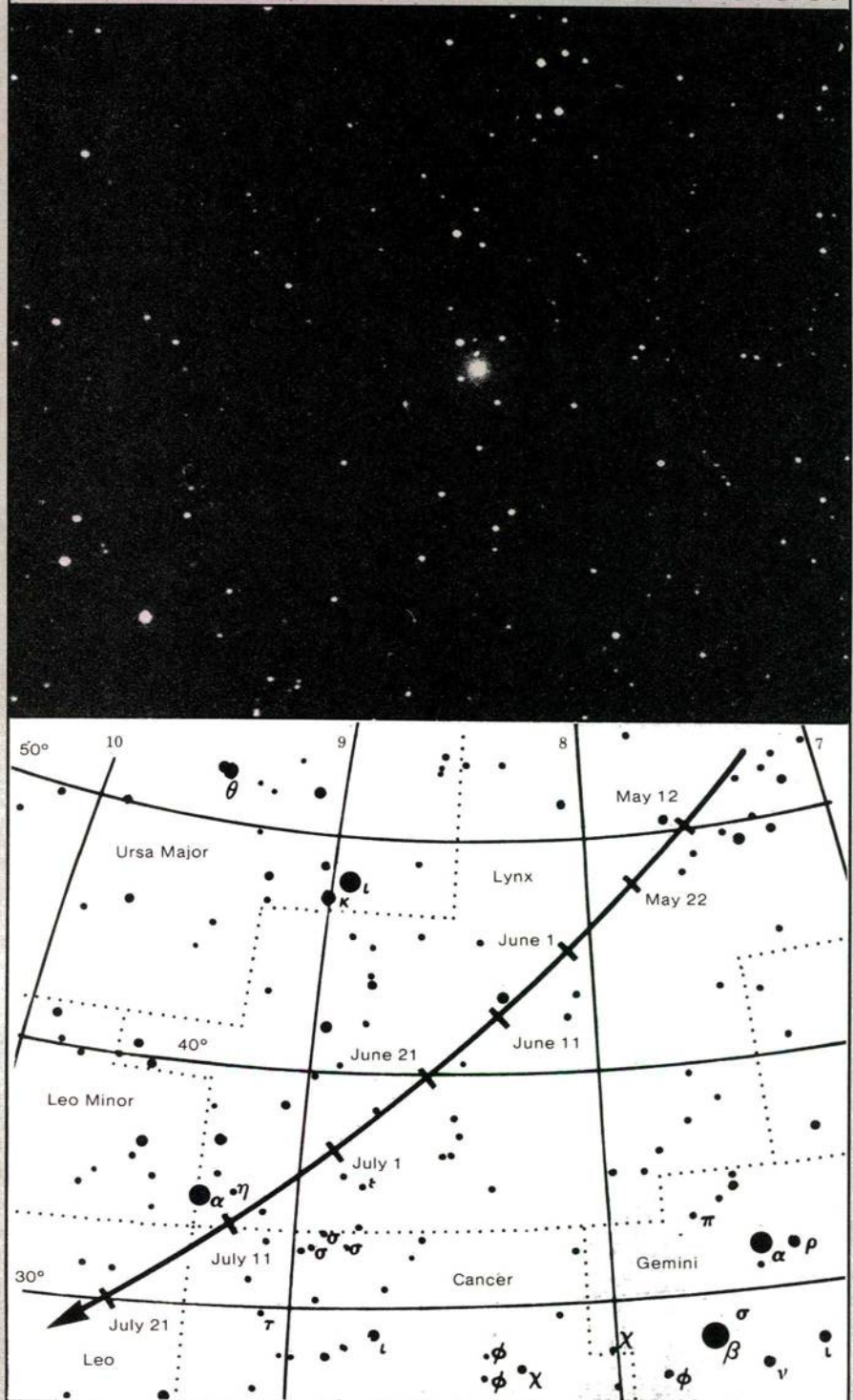
"The inverse relation between activity as indicated by sunspot number, and reduced temperature, is clear," Livingston reported in a recent issue of *Nature*. He was referring to the observed correspondence between the 11 year cycle of activity on the sun and temperatures and rainfall on Earth, which also seem to go up and down every 11 years. These sun-Earth links are only just starting to be explored by astronomers and geophysicists.

No one knows why the sun should cool down as its activity increases. The cooling is expected to continue as the current cycle of activity develops, although at solar maximum the sun's average surface temperatures may well rise again because the bright patches known as faculae then become more abundant.

More details about the changes in solar radiation will be given by the Solar Maximum Mission satellite, which is scheduled for launch in 1979. ☛

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Comet Meier: 1st Comet Discovered From Canada



Comet Meier is shown 48 hours after its discovery, in a 15 minute exposure on 103aF film using a 12-1/2 inch reflector at f/4.6. Photograph by Jack Newton.

Canadian observer Rolf Meier discovered the 10th magnitude comet, whose path through the constellation Lynx is shown, on April 27, 1978. He found the comet, the first ever discovered from Canada, using the 40cm f/5 reflector at Indian River Observatory of the Royal Astronomical Society's Ottawa Center. Comet Meier was three astronomical units from the sun on April 27, and will be at approximately that same distance from Earth when it becomes lost in the twilight at the end of July, gaining one magnitude in the interval. At the time of perihelion on Nov. 8, it will be too close to the sun to be visible.

Evidence Indicates Black Hole in M-87 Galaxy

The best evidence yet for the existence of a supermassive black hole outside our galaxy has been discovered by an international team of astronomers. Their studies of the galaxy M-87 have revealed the existence of a dark object in its center, roughly five billion times the mass of our sun.

Their discovery is important because it represents the first observational evidence for an object that astronomers have postulated as a fundamental source of large scale high energy processes in the universe. According to theory, enormous black holes could power such objects as quasars and radio galaxies, which emit prodigious amounts of energy.

Black holes currently hold a precarious position on the borderline between scientific theory and reality. There is evidence for smaller black holes, around 10 times the mass of the sun, within our galaxy. These are thought to be the corpses of huge stars, greater than about 20 times the mass of our sun, which exhausted their nuclear fuel and collapsed into superdense objects. Their gravity is so powerful that no matter or energy, even light, can escape from them.

Only extremely massive black holes, however, such as the one indicated for M-87, satisfy the requirements of energy sources for the incredible high energy processes now known to exist in the centers of galaxies and quasars. According to theory, energy is produced by a black hole when matter falling toward it is accelerated by its very large gravitational field and is heated to very high temperatures.

Evidence for a black hole in the center of M-87 was reported in two papers in a recent issue of the *Astrophysical Journal*.

In the first, the astronomers — Peter J. Young, James A. Westphal, Jerome Kristian and Christopher P. Wilson of Hale Observatories, and Frederick P. Landauer of Caltech's Jet Propulsion Laboratory — described the discovery of an excess of light in M-87's center, which cannot be explained by common theories of how galaxies are normally structured. This "spike" of excess luminosity means that there exists a high concentration of stars in the galaxy center, bound to some large mass.

The astronomers were able to achieve fine resolution and high accuracy in examining the light from the galaxy by using sensitive electronic television cameras attached to the 60 and 200 inch

telescopes at Palomar Observatory. These detectors, called Silicon Intensified Target tubes and Charge Coupled Devices, have greatly increased the sensitivity with which astronomers can examine the light from stars and galaxies.

In the second paper, the astronomers — Wallace L.W. Sargent and Peter J. Young of Hale Observatories, Alec Boksenberg and Keith Shortridge of University College London, C. Roger Lynds of the Kitt Peak National Observatory, and F.D.A. Hartwick of the University of Victoria, British Columbia — described how they measured the mass in the center of M-87 and found that about five billion solar masses could not be accounted for by usual conglomerations of stars.

To determine the mass of the core of M-87, the astronomers measured how spectral lines in the light from the galaxy were broadened from their usual sharpness. The faster a population of stars moves about in relation to one another — its *velocity dispersion* — the broader are the spectral lines the galaxy emits. Such measurements enabled the astronomers to calculate how much mass existed in the galactic center, because they could determine from the velocity dispersion of the nucleus, and its size, how much mass would be required to keep the stars within the nucleus.

The measurements of the spectrum of M-87 were performed on the four meter telescope at Kitt Peak National Observatory. The high resolution spectra were obtained using a device known as an Image Photon Counting System (developed by Boksenberg). The device has a special intensifying television camera which amplifies the extremely faint images from the telescope more than 10 million times.

The combination of data from the two papers reveals that, despite the excess concentration of bright stars in the center of M-87, far more mass exists than can be accounted for by the stars whose light is visible. In the nucleus of M-87, there appears to be about 60 solar units of invisible mass for every solar unit of luminosity. This compares with a mass-to-luminosity ratio of six for the main body of M-87 and for the normal galaxy NGC-3379, which the astronomers studied for comparison.

This means that there is an enormous, dark mass which profoundly affects the movement of stars in the center of M-87. The astronomers' measurements show that this mass must exist in the central

300 or so light-years of the galaxy — a tiny volume that is 100,000 light-years across. The best candidate for such a high mass, low volume dark object, according to the astronomers, is a black hole. Theoretical computations by Young show that such a black hole would explain the observations, and that stars falling into the black hole from the galaxy could provide the fuel for the very energetic processes that are occurring in M-87.

"While our findings do not prove finally that M-87 contains a supermassive black hole, the central mass is very peculiar, and a black hole is in many ways the most attractive explanation for what we've detected," said Kristian. "With these observations, we've pushed our instrumentation nearly to the limit," he said, "and not until the Space Telescope is operational in 1983 can we hope to obtain much better resolution of such objects, and to test the black hole model with much greater precision."

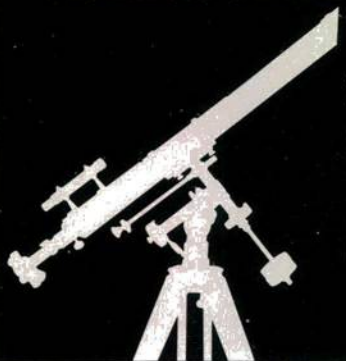
M-87, first cataloged by 18th century astronomer Charles Messier, is a member of the nearest great galactic cluster, in the constellation Virgo. It is about 65 million light-years from Earth, making it the nearest example of a galaxy with a very active nucleus. M-87 is about 100 times more massive than our own, and is the source of strong radio frequency and x-ray emissions, which indicate violent activity taking place within it. M-87 is also unusual because it possesses an enormous jet extending outward from its nucleus, indicating a vast expulsion of matter and energy.



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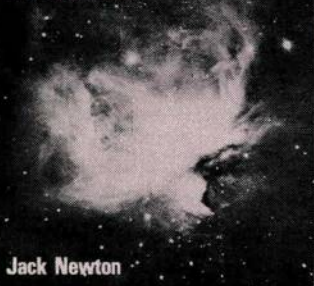
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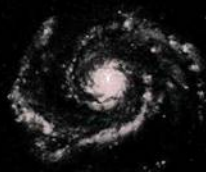
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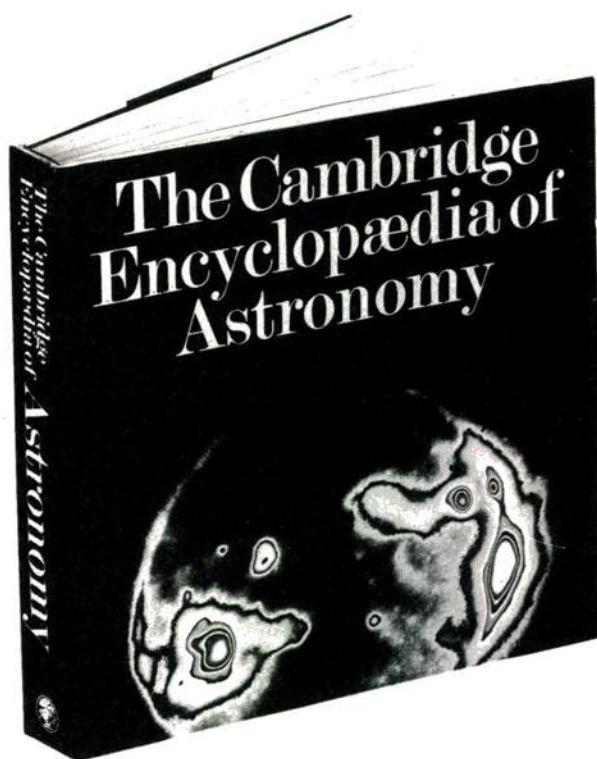
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STAR DOME

JULY

by

Henry J. Phillips and James Mullaney

Three related zodiacal constellations dominate the southern sky this month for observers in midnorthern latitudes. The three are Scorpius the scorpion, Ophiuchus the serpentholder, and Sagittarius the archer. All three are large, contain bright stars, and are traversed by the Milky Way.

We're not accustomed to thinking of Ophiuchus as a zodiacal constellation; it's never listed among the "official" 12. But a look at any star atlas will reveal that Ophiuchus contains quite a lengthy piece of the ecliptic (the path along which sun, moon and planets appear to travel) within its borders — much more, in fact, than neighboring Scorpius, which definitely is an "approved" member of the zodiac.

Why is Ophiuchus neglected in this way? We certainly can't claim that it's because of any lack of brightness; Ophiuchus is a more prominent group than Cancer, Capricornus, Aquarius, Pisces or Aries, all of which are in the zodiac. Nor can we say that it's because the ecliptic doesn't run through the center of the constellation; in Pisces and Aries, for example, the ecliptic runs through the southern ramparts of each constellation, just as it does in Ophiuchus.

The answer to the puzzle may lie in the fact that Libra, Scorpius' next-door neighbor to the west, was once a part of Scorpius. When those two groups formed one large constellation, Ophiuchus could have been a full-fledged member of the zodiac and there would still have been a convenient 12 star groups (one for each month) in this select band. But when Libra was separated from Scorpius and became a constellation in its own right — situated right smack on the ecliptic — prominent wise men must suddenly have realized that the zodiacal constellations now numbered an unlucky 13, and one had to go. Scorpius, though mostly located well south of the ecliptic, was brighter and easier to spot than Ophiuchus, so the latter suffered the ignominy of exclusion from the zodiac.

Unfortunately, when the official constellation boundaries were adopted in 1930 by the International Astronomical Union, those of Ophiuchus and Scorpius were delineated in such a way that Ophiuchus wound up with more of the ecliptic than Scorpius had. As we now have it, the sun spends only *five days* in Scorpius, while dawdling for 23 in Ophiuchus! Also, the planet Neptune has been located in Ophiuchus for several years now, and some of the brighter planets (Mars and Jupiter) will be reaching opposition within its borders during the next decade.

But just as astrologers have ignored the movement of the vernal equinox over the past 2,000 years, they have also chosen to ban Ophiuchus from their official zodiacs. What would a person born under Ophiuchus be like?

We mentioned that Ophiuchus, Scorpius and Sagittarius are related constellations, and they are in one somewhat convoluted Greek story. Ophiuchus was meant to represent Asclepius, a son of the god Apollo who was well versed in the art of healing. So proficient was he at his occupation that he even learned how to bring the dead back to life — a risky bit of knowledge, since it aroused the wrath of Hades, god of the underworld. Things were bad enough while Asclepius was raising simple, nondescript Greek peasants from the dead, but Hades finally lost all patience when Asclepius attempted to revive the hero Orion.

In one of her innumerable fits of jealousy, the goddess Hera had had Orion killed by the sting of an enormous scorpion that she raised up from Earth. Such a wound was child's play to Asclepius' powers, however, and he brought Orion back without hesitation. But Hades, who had apparently been eagerly awaiting the entry of Orion into his domain, was livid with rage and ordered his younger brother Zeus, king of the gods, to "do something"! Zeus thoughtlessly took the easy way out and zapped As-

clepius with one of his omnipresent, thunderbolts. Repenting of the deed, however, Zeus placed Asclepius among the stars.

Later when Orion died again (murdered this time by the goddess Artemis — Orion certainly was unpopular among goddesses!), he too was immortalized in the stars. Hera, not about to take glorification of her foe lightly, demanded that her pet scorpion be placed in the sky also. Zeus complied, but took the precaution of putting the scorpion at the opposite side of the heavens from Orion, so the two wouldn't meet again and cause even more havoc. As a result, Orion sets as Scorpius rises. (Some say that Orion is hastening away in fear — which should not be unexpected; true courage was never one of Orion's strong points.)

Zeus also was careful to place the scorpion under careful guard; not only is Asclepius nearby to head off any trouble, but also Chiron, the wisest of the centaurs (depicted in the constellation Sagittarius; see the May 1978 Star Dome for more details). Chiron is usually drawn as aiming an arrow toward the scorpion's heart. If we look at the arrangement of stars in this area, though, we might choose to see Sagittarius' famed asterism, the teapot, about to pour some hot tea on the scorpion's upraised sting — which would likely set off a real free-for-all in the vicinity.

The teapot of Sagittarius is formed in the following manner: The stars Sigma (σ), Tau (τ), Zeta (ξ), and Phi (ϕ) Sagittarii mark the pot's handle. Gamma (γ), Delta (δ) and Epsilon (ϵ) Sagittarii form the teapot's triangular spout while Lambda (λ) Sagittarii marks the tip of the pot's lid. The Milky Way rises from the spout like a cloud of steam.

Another well-known asterism found in Sagittarius is called the Milk Dipper — a miniature version of the Big and Little Dippers to the north. The stars of the teapot's handle form the bowl of this dipper, while Lambda and Mu (μ) Sagit-

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, asteroids, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page 28.





tarii mark the handle. The Dipper is about to scoop some milk from the Milky Way; perhaps it intends to dash this over the scorpion, too, thus cooling it off a bit — unless it merely serves to make an angry scorpion even madder.

For those who prefer to see the archer and his bow, three of Sagittarius' stars — Lambda, Delta and Epsilon — have appropriate names. Respectively, they are Kaus Borealis, Kaus Media, and Kaus Australis. These names merely mean the northern, central and southern parts of the bow. Kaus Asutralis is one of Sagittarius' two second magnitude stars; the other is Sigma, which also goes by the name Nunki.

As our Close-Up section below indicates, Sagittarius is simply crammed with fascinating deep sky objects for the observer with a telescope. But even if you have only your eyes to use, you can enjoy the sight of the magnificent Sagittarius starclouds as the Milky Way rises, as it does every summer, from the southern horizon.

Close-Up

Sagittarius Region (Part 1)

This month we begin Star Dome's first two-part Close-Up — a measure necessitated by the overwhelming richness of the Sagittarius region. The heart of our galaxy lies in this direction, and the Milky Way starclouds are even more dense and brilliant than those farther north in Cygnus. No less than 15 of Messier's clusters and nebulae await our inspection, along with hosts of NGC objects, variable and highly tinted suns, and star chains and asterisms. Strangely, the only heavenly treasures in short supply in this magnificent region are prominent double and multiple stars!

Our coverage of Sagittarius this month concentrates on the superb Milky Way area in this constellation's north-western corner — roughly that part of the sky west of 19 hours right ascension and north of about -30 degrees declination. Next month we will explore its more far-flung ramparts — especially its remarkable array of globular clusters that parallel the flow of the Milky Way down the heavens.

M-17

We'll begin with the farthest north of this month's showpieces and work our way southward. Our first stop is the bright diffuse nebula M-17, the well-known Omega or Horseshoe nebula. It's named for an arch of nebulosity connected at one end to a long, tapered ray. It was thought by its name to resemble a capital Greek letter omega (ω), but to us today it has the appearance of an extended figure 2 or checkmark in the sky. It can easily be picked up in binoculars and finders about 2-1/2 degrees south-

east of Gamma (γ) Scuti, due north of the teapot.

This is one of Messier's objects that has a "dual personality", for it's listed in catalogs as both a diffuse nebula and a loose, irregular star cluster! The nebula itself measures more than 1/2 degree in extent and glows near seventh magnitude visually. The associated cluster contains some three dozen components spread over an area 22 minutes of arc in extent, north of and roughly parallel to the long ray. Both objects are well seen in a four inch telescope at low to medium magnification, as indicated in our sketch.

M-17 looms large on dark nights in eight inch and larger apertures, and ranks as one of the finest diffuse nebulae in the heavens — second only to M-42 in Orion and perhaps the Lagoon (described below) for northern observers. Such instruments show a long bright ray, hooked at one end, and crossed by dark obscuring dust lanes. Adding to the beauty of the scene is a bright sprinkling of glittering suns, along with the rich Milky Way background.

M-18

Just one degree south of M-17 is a coarse stellar assemblage designated M-18. Here we find a dozen or so suns in an area 12 minutes of arc in size, shining with the combined light of a 7.5 magnitude star and easily seen in a finderscope. Although sparse and rather small as open clusters go, this clan is well worth inspection while you're in the vicinity.

Webb described M-18 as lying in a "glorious field in very rich vicinity; south lies a region of surpassing splendor". Bernhard, Bennett and Rice called this object a "glorious star cluster", while Holyoke pointed out that "its beauty lies in the beauty of the whole brilliant area. The cluster itself is bright but scattered and not very easy to separate from its surroundings."

Even a two inch telescope at just 30 power shows this object nicely against the Milky Way background, and more magnification begins to spoil the effect by spreading the stars unduly. M-18 is perhaps at its sparkling best as seen in four to six inch richest field telescopes at 15 to 25 power. In such instruments, its splash of bright and faint suns flicker like cosmic fireflies in a midsummer night.

M-24

About a degree southwest of M-18, and two degrees northeast of Mu (μ) Sagittarii, we run into another open cluster — this one offering a number of puzzles for the visual observer. M-24 is a tight grouping of some 50 suns in an area only four minutes across, and glowing near 4.6 magnitude. You may have difficulty identifying it in a typical find-

20h

19h

18h

-10°

-10°

0°

0°

-10°

-10°

-20°

-20°

-30°

-30°

-40°

-40°

AQUILA

SCUTUM

SERPENS

OPHIUCHUS

Sagittarius

SCORPIUS

CORONA AUSTRALIS

TELESCOPIUM

CAPRICORNUS

MICROSCOPIUM

6818

6822

V1942

AQ

 ρ_1 ρ_2

M16

M17

M18

M24

M25

M23

M21

M20

M8

M22

M28

M29

M75

Ecliptic

RR

h5188

M55

 θ_2 θ_1

M54

M70

M69

h5149

6723

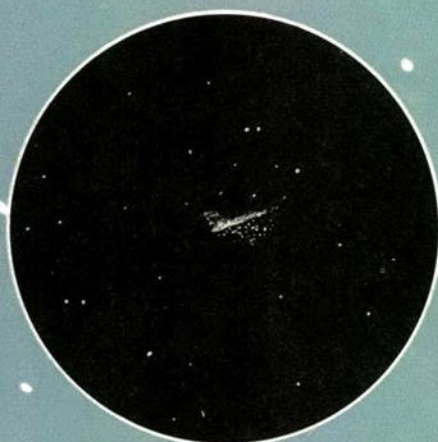
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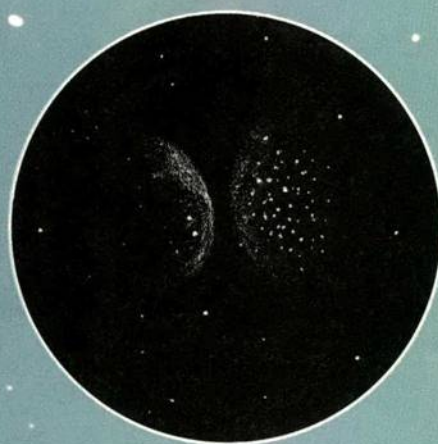
M-17



70x

N

M-8



100x

N

er, but a three or four inch telescope shows it distinctly at 45 to 90 power.

M-24 is considered rich, concentrated and rather small for an open cluster, reminding some observers of a globular cluster. Indeed, Chambers considered it a "globular cluster of small stars...in a superb field of stars". Muirden likewise described it as "a globular cluster, visible as a nebulous patch, lying on the edge of a region of indescribable richness". How does it look to you in your telescope at various magnifications and on different nights?

Another uncertainty concerning M-24 is the exact identity of the tiny cluster itself amid the great starcloud in which it resides. Many observers apparently mistake the latter for the former, resulting in a confusing state of affairs. Barns, for example, logged M-24 as a "giant cluster", while Norton stated: "M-24 itself is really a detached part of the Milky Way; in it is a true, faint cluster, NGC-6603." The NGC gives M-24 as NGC-6603, describing it as "Remarkable.

Above: M-17, the Omega nebula, is one of the brightest and most prominent of the diffuse nebulae. It is well seen at low power, as shown in our drawing made from a four inch reflector at 70 power. Left: M-8, the Lagoon nebula, is a birthplace of stars. Through the eyepiece, it has the appearance of a large nebulous cloud divided in two by a dark rift, and associated with a large open cluster of stars. Our drawing shows the view through an eight inch reflector at 100 power. Drawings by James Mullaney.

Cluster, very rich, very much compressed, round, stars 15th magnitude (Milky Way)." Note that no mention is made of this object's size, which might help settle the matter. No less an observer than Sir John Herschel himself was even confused here, for an NGC footnote on M-24 states: "John Herschel's two observations hardly consistent with this description, and their deviation of nearly +3 minutes from Messier's place makes it very doubtful whether he really saw this object."

Most Messier authorities consider M-24 to be the small compact cluster; these include Holyoke, who stated: "This cluster is much more of an entity [than M-18]. It is brighter, more compact, and stands out from the background." He recommended 100 power on a six inch reflector for a "splendid view" of this object. Webb described it as being in a "magnificent region, visible to the unaided eye as a kind of protuberance of the galaxy". All of which brings up the fascinating question — especially to holders of the coveted Messier Club Certificate: Have you really seen M-24?

M-23

Five degrees due west of M-24 and some four degrees northwest of Mu Sagittarii is yet another open cluster — one that leaves no doubt about its identity. This is M-23, perhaps the finest representative of its class in this entire region. It boasts at least 120 stars spread over an area 25 minutes in size (some authorities make it twice this apparent size) and glowing near seventh magnitude.

In six inch and larger telescopes, this stunning stellar commune is a marvelous sight! Its outline is somewhat elongated and the stars seem arranged in festoons. Holyoke considered it "a large, rather scattered open cluster" and stated that "35 power on almost any telescope will find and resolve it". Webb saw it as a "Grand low power field...Announced by increasing number", and Barns as a "blazing wilderness of starry jewels"! Its soft radiance comes to us from across more than 2,000 light-years, or 12 quadrillion miles of interstellar space.

M-20

Continuing our excursion down the summer Milky Way, we find, three degrees southwest of Mu Sagittarii, the fainter of two famous diffuse nebulae that are situated just two degrees apart on the sky. This is the often photographed rose and blue cloud of gas known as the Trifid nebula, or M-20. This circular smear of light is 1/2 degree in diameter, and is crossed by three dark rifts or lanes of obscuring matter, which meet at its apparent center and give the Trifid nebula its name.

You may find M-20 disappointing at

Selected Objects — Sagittarius Region (Part 1)

Object	Type	Mag.	Size/Sep.	R.A. (1950)	Dec.
X Sagittarii	V:7.0 ^d	4.8-5.8	—	17 ^h 44 ^m	-27°49'
* M-23	OC	6.9	25'	17 ^h 54 ^m	-19°01'
h-5003	★2	5.3, 7.0	6"	17 ^h 56 ^m	-30°15'
* M-20	DN	5?	27' x 29'	17 ^h 59 ^m	-23°02'
M-21	OC	6.5	10'	18 ^h 02 ^m	-22°30'
* M-8	DN	4?	35' x 60'	18 ^h 02 ^m	-24°20'
* NGC-6530	OC	6.3	10'	18 ^h 02 ^m	-29°35'
W Sagittarii	V:7.6 ^d	4.7-5.9	—	18 ^h 02 ^m	-30°44'
Hd-149	★2	5.6, 7.9	4"	18 ^h 07 ^m	-18°27'
* M-24	OC	4.6	4'	18 ^h 16 ^m	-17°09'
* M-18	OC	7.5	12'	18 ^h 17 ^m	-16°12'
* M-17	DN/	7	37' x 46'	18 ^h 18 ^m	-24°54'
* M-28	OC	7.5	22'	18 ^h 22 ^m	-23°14'
NGC-6629	GC	7.3	5'	18 ^h 23 ^m	-19°17'
M-25	PN	10.6	14' x 16"	18 ^h 29 ^m	-23°58'
* M-22	OC	6.5	40'	18 ^h 33 ^m	
	GC	5.9	17'		

* Detailed in Close-Up

★2 = Double Star
V:#^d = Variable Star, period
DN = Diffuse Nebula
PN = Planetary Nebula

OC = Open Cluster
GC = Globular Cluster
Mag. = Magnitude
Sep. = Separation

first sight, for its light is spread over an area nearly that of the full moon, resulting in a relatively low surface brightness. Slow sweeping back and forth across this object in a four inch scope at 90 power or so reveals it to be much larger than your first impression. A double star can be seen near its center where the rifts come together, but you'll need at least an eight inch aperture, a dark night and averted vision to glimpse the rifts themselves.

Chambers described M-20 as "an open cluster of stars, superposed upon a singular trifold nebulous mass. Requires a large telescope." Bernhard, Bennett and Rice logged it as "very large and bright, divided into irregular sections by dark lanes. Called a remarkable and curious nebula. With double and multiple stars." Webb saw here a "cruciform group. Very curious object; pair with minute comes 'where the ways meet', dark rifts through nebulosity....Nebula imperfectly seen by Smyth as well as myself; rather low. Grand region."

From the low latitude and clear skies of southern California, Barns found M-20 in his 10 inch reflector "a dark night revelation, even in modest apertures. Bulbous image trisected with dark rifts of interposing opaque cosmic dustclouds....Outlying areas rich in stars in cruciform and other symmetries." Holyoke considered it "spectacular on a good night" and remarked that the cruciform group "is very apparent in a six inch telescope, but is definitely not the dominant feature of the field".

Interstellar clouds like the Trifid and Lagoon (described below) are, in reality, giant stellar incubators in which new stars (and planets?) are being formed right before our eyes! Even though the gossamer radiance we see from M-20 has been traveling through space for more than 35 centuries to reach us, the cloud must look much the same now as it did back then, for centuries are but seconds in the life of a star — mere ticks on the cosmic clock!

M-8 and NGC-6530

Located two degrees south of the Trifid is the well-known Lagoon nebula, M-8. Unlike its neighbor, this object is anything but disappointing, even in a small telescope. Indeed, this bright cosmic cloud is striking in any instrument from binoculars to larger sized telescopes.

Like M-17, M-8 has a "dual personality" — it's both a diffuse nebula and an associated star cluster. The former is M-8 itself — a large glowing patch some 35 by 60 minutes in overall extent, traversed by a colossal vertical dark rift. The scattered open cluster is a clan of hot newborn stars lying to one side of the nebula. Designated NGC-6530, the cluster has several dozen blue-white members in an area 10 minutes or so across. The combined light of both nebula

and cluster is nearly that of a fourth magnitude star, making this object a naked eye wonder despite its distance of nearly 4,500 light-years.

The glowing nebula, obscuring rift forming the "lagoon" and cluster, are all within easy reach of a three or four inch telescope at just 45 power. Eight inch and larger instruments at medium to high power allow glimpses of detailed structure within the nebula (like the milky streaks and loops reported by John Herschel), and give the suggestion of color tints. Our drawing presents the view as seen through just such an instrument.

Chambers considered M-8 an "irregular cluster with nebula adjoining. A pretty low power field." Norton saw it as "an ill-defined nebulosity with dark patches and stars, followed by an irregular open cluster". And Brown recommended that we "view this in the fall of the year to get the 'black velvet' sky needed to show the nebulosity surrounding the stars".

Webb called M-8 a "splendid galaxy object; visible to the naked eye. In a large field we find a bright coarse triple star, followed by a resolvable luminous mass, including two stars, or starry centers, and then by a loose bright cluster enclosed by several stars; a very fine combination." Barns found here a "myriad of low magnitude stars, and a few brighter units resembling somewhat the Pleiades, involved in wide wastes of incandescent hydrogen and helium, over-flung with dark absorbing patches. A naked eye wonder."

Pickering included it in his prestigious roster of the sky's finest showpieces, calling it the "Nameless Nebula in Sagittarius" (apparently Pickering wrote before M-8 had been dubbed the Lagoon) and noting: "Conspicuous to the naked eye, chiefly on account of the cluster of stars with which it is associated. Some dark lanes within it can be faintly traced similar to those seen in the Trifid which is near it, and distinctly inferior." Holyoke regarded M-8 as "a very good rival for the Orion nebula" and pointed out that unlike most diffuse nebulae, "the nebulosity is not lost and the stars stand out beautifully" at high powers.

The Lagoon is generally considered one of the three finest objects of its class for northern hemisphere observers, along with the Orion and Omega or Horseshoe nebulae. Do you agree with this assessment?

M-28

As a prelude to our final offering, take a quick look at the little globular cluster M-28, situated just one degree northwest of the star Lambda (λ) Sagittarii at the top of the teapot. This seventh magnitude circular glow measures five minutes in apparent size and is rather highly concentrated as globulars go.

Webb considered this dense stellar swarm "not bright", but Holyoke stated "this one is small, compact and bright", and Muirden's impression was "a small, bright globular cluster with a blazing center". M-28 is easily picked up in a three inch telescope at 45 power, but at least a six inch at medium to high magnification is required to resolve its outer edges into individual stars. While not an impressive object itself, it does serve to accentuate the magnificence of our next and final selection by way of contrast.

M-22

We conclude this first part of our survey of the wonders of the Sagittarius region by offering one of the finest globular star clusters in the heavens for your contemplative scrutiny. This is M-22, easily found in a finder two degrees northeast of Lambda Sagittarii. With a total brightness near sixth magnitude, it can be seen without optical aid in a dark sky and has been known since at least 1665 — a century before Messier.

This glorious orb measures at least 17 minutes in diameter and is classified as medium in concentration. A three inch refractor at 45 power shows a fuzzy ball of light and begins to resolve its outer members. M-22 is resolved into stars right to its core in six inch and larger telescopes at medium magnifications, while 10 and 12 inch apertures reveal the brighter units as ruddy in color on a good night.

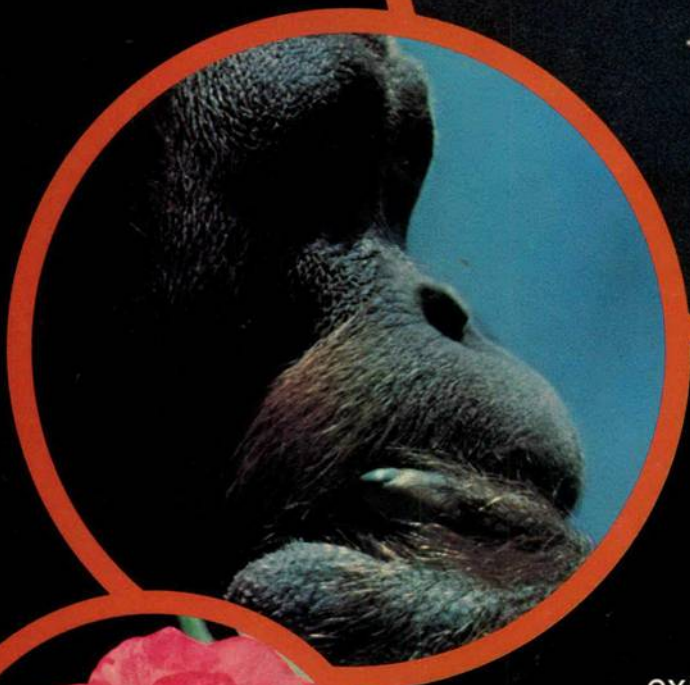
Most observers rate M-22 as the finest globular visible from northern latitudes after the Hercules cluster (M-13). Holyoke, for example, felt it "the equal of, or very much like, M-13 in Hercules", while Barns considered it "another colossus, $\pm 1/2$ degree in extent, larger and brighter than M-13, tho less condensed". And again, it appears on just about everyone's list of the best, including Pickering's.

Muirden recorded M-22 as "a superb globular cluster, partly resolved with a small telescope". Norton remarked: "The larger (brighter) stars are ruddy." Webb's account of this showpiece is more detailed: "Beautiful bright cluster, very interesting from the visibility of components, largest 10 and 11 magnitude, which makes it a valuable object for common telescopes, and a clue to the structure of many more distant or difficult nebulae. John Herschel makes all the stars of two sizes, 11 and 15 magnitude, as if 'one shell over another', and thinks the larger ones ruddy."

This vast stellar beehive lies within 10,000 light-years of us, making it among the closest objects of its class and one of the grandest sights in the entire heavens. As you gaze into its awesome glittering core, you'll understand the meaning of Walt Whitman's inspired observation: "Every cubic inch of space is a miracle."

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